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PROCEEDINGS OF THE 1968 UNITED STATES ARMY OPERATIONS RESEARCH SYMPOSIUM - 22-24 MAY 1968 PART I

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Operations Research Symposium

U. S. ARMY RESEARCH OFFICE-DURHAM

DURHAM, NORTH CAROLINA

22-24 May 1968

Proceedings - Part I

OFFICE CHIEF OF RESEARCH AND DEVELOPMENT

PROCEEDINGS

of the

United States Army

OPERATIONS RESEARCH SYMPOSIUM

22-24 May 1968

PART I
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U.S. ARMY OPERATIONS RESEARCH SYMPOSIUM

22 - 24 May 1968

FOREWORD

The 1968 U.S. Army Operations Research Symposium is the seventh annual symposium in the Army series, which is sponsored by the Office of the Chief of Research and Development, Department of the Army. This symposium was planned, managed, and hosted by the U.S. Army Research Office-Durham in Durham, North Carolina.

This volume, Part I, is unclassified and contains all invited and contributed papers as well as the major addresses which were presented in the unclassified sessions. A second volume, Part II, contains the papers and addresses which were presented in the classified sessions.

Donovan F. Burton

DONOVAN F. BURTON
Colonel, GS
Commanding
U.S. Army Research Office-Durham

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*The remarks of Dr. Arthur C. Herrington, Director of Naval Programs, Office of the Assistant Secretary of Defense (Systems Analysis), were presented at the symposium but do not appear in these Proceedings. The author welcomes individual inquiries.

OPENING REMARKS

Colonel Nils M. Bengtson
U.S. Army Missile Command
Redstone Arsenal, Alabama

The Foreword in the Program mentions that this is the Seventh Annual Operations Research Symposium. Those who have been associated with these symposia over the years recall that actually there were a few symposia attended by a large segment of the Army prior to the first in the series of seven, which started in 1962. The record of the Durham offices in these conferences extends back some 11 or 12 years. Over the years it has been the purpose of these meetings to stress the importance of operations research and systems analysis in the activities of the Army and to serve as a showcase to the Army for operations research being performed by military and civil service engineers and analysts. The Proceedings of the conferences are valuable documents and serve as the actual showcase for the papers of Army personnel. Preprints of the Unclassified Contributed Papers for this meeting are available.

WELCOME

Colonel Donovan F. Burton
Commanding Officer
U.S. Army Research Office-Durham

Good morning, Gentlemen:

This is the 7th Army Operations Research Symposium. Traditionally, there have been several objectives to be secured by these symposia held annually thus far. Very briefly those objectives are to:

a. Emphasize the role of operations research in the improvement of military operations.

b. Acquaint key personnel of the Army with in-house capabilities.

c. Provide a forum for presentation and discussion of Army problems.

d. Inform participants of new technological developments.

e. Increase applicability of results obtained in O.R. studies.

f. Further personal acquaintances of operations analysts.

Broadly speaking, the objectives might be summed up by saying that the symposia are attempts to spread the word on operations research and systems analysis to Army people as a way of thinking about problems. Appropriately, this way of thinking should have behind it quantification of facts and perhaps probabilistic statements about relevant but incomplete information, such that the appropriate methodology can be brought with strength against the problem itself. Even if the facts and relevant information are not quantified, the logical way of thinking employed by the analyst is an end in itself. Thus it is that we hope to talk about operations research and systems analysis during this symposium with view to obtaining their broad practice throughout the Army.

It is interesting to note the growth of military participation in these symposia. In 1962 there were three military speakers and twenty-four civilians. The ratio varied during the intervening years to the point that in this symposium 20 speakers are military and 28 are civilians. The percent military is 41.7 in 1968, versus 11.1% in 1962. Fitting a straight line by least squares to all points one finds the mean increase per year is 3.8%. The increase is significant to the .05 level!

I should like to offer some explanation about the agenda. We tried to design it with some logic so that plenary sessions would provide some basis for the more detailed presentations in simultaneous sessions. Force planning seemed to us to be almost all encompassing so we started with it. The intelligence base for force planning could then be looked at along with weapons consideration. A look at the Vietnam situation could provide some

intuitive assessment of previous force planning for that contingency. We then felt it might be useful to discuss the meaning of operations research and systems analysis, followed by papers representing one or the other. Last, we wanted to take some look into the future, and for this purpose established a working group to discuss areas in which the military can profit by further research.

I must say the response for participation has been overwhelming. We received some 60 contributed papers of great variety. This in itself attests to the growth of operations research interest in the Army. Unfortunately, we could use only 15 of them in the limited time available but there was the advantage of more selectivity for those to be presented. It might also interest you to know that approximately 35% of those assembled here are participants in one way or another in the proceedings.

Now if I may make a few personal remarks. I believe very strongly that progress is made through people working together to integrate their various talents and energies. To the extent that OR and SA studies provide order and rationality in this direction the more effective people will be. OR and SA studies do not provide action but merely indicate direction of action. The proof of their value lies in the accomplishments by people not as planners but as operators. Consequently, there must be a preponderance of belief in the values of such studies by those who execute if their committed effort is to be obtained. It seems to me that OR and SA analysts must keep one eye turned toward those who will implement the required actions. This may be asking too much of the analyst but certainly somewhere in the decision, the propensities of the action agencies must be examined. TFX may be a notable example of such a need. Secondly, a lesson learned by the British during World War II days may have been forgotten. Many of you will recall the "Sunday Soviets" which were successful meetings to achieve problem definition. You will recall perhaps the tremendous variety of talent brought together in the Soviets extending from the user of military systems to representatives of diverse disciplines. The product of their discussion was a scientific and meaningful statement of the problem. Crowther and Whiddington in their book "Science at War" in talking about the Sunday Soviets considered the statement of the problem as half the solution. Perhaps we need to give more attention to problem formulation.

Gentlemen, I hope you have a stimulating and meaningful experience at this symposium. Perhaps the ideas expressed here will contribute to your efforts in your organization. We could ask no more. Let me extend to each of you a sincere welcome.

OPERATIONS RESEARCH AND SYSTEMS ANALYSIS
ITS USE BY THE ARMY

Brigadier General C.D.Y. Ostrom, Jr.
Director of Army Research

At the charm course for new stars, the students were reminded that a remark by a senior colonel was an expression of opinion while the same words spoken by a junior BG were a statement of policy. You had better consider the speaker a senior colonel for the next several minutes.

First, I consider that systems analysis is either what was called engineering economics or else is intelligent and methodical design. Such a definition makes systems analysis a specialized fraction of operations research, so I'll just talk about operations research and the Army. If the thoughts expressed conflict with the panel discussion tomorrow morning of "Operations Research/Systems Analysis - What Are They," lay it to the hazard of not presenting the speaker with his text.

Second, the Army as a whole does not make maximum use of the art and maybe doesn't understand what operations research is.

Third, the Army used operations research long before the phrase was coined and is a massive user of many facets of the art. The formal staff study and the estimate of the situation were widely used prior to 1940 and are both classic examples of operations research. The Army Air Forces and the antiaircraft artillery used the methodology as presently defined extensively in WW II. The Ordnance Corps was applying it to weapons systems analysis prior to 1948, and its use is all-pervasive in the Army General Staff, the Army Materiel Command, and the Combat Developments Command today.

Troubles seem to surround its use despite its age and presumed familiarity. I will discuss some of these apparent difficulties at the risk of repetition and oversimplification.

What is operations research? It is a staff action to support the commander and aid him in his decision-making. An ideal staff study needs only an initial in the Approved or Disapproved box. If the guidance was imcomplete or incorrect, then See Me is checked. Guidance generally applies to the Assumptions, less often to Facts Bearing on the Problem. And See Me is most likely to deal with Assumptions. Another possible reason for that See Me is that the methodology or Discussion is obscure. The end result is that the commander is dubious about the conclusions and recommendations.

Let's expand on these ideas a little to examine implications. First, let's look at an organizational relationship. The decision-maker is responsible for guidance, particularly on policy. If it is too vague initially, he should expect some discussion with his action officers to

refine it, the See Me. Guidance or assumptions have another idiosyncrasy. The implications of a change in assumptions may not be clear to anyone concerned. Thus the staff officer should make occasional sensitivity analyses in the course of the study to determine the relationship of assumptions and conclusions. If he finds a great deal of sensitivity, then he should actively seek the See Me in order to have the guidance refined. A definitive study can hardly be expected if there are no bounds placed on its scope. The effort becomes a talking paper, an item of value in itself, but hardly operations research.

The next man or group in the act is the staff. They are the executors of the study. Their role with respect to the Assumptions has been outlined. They also are responsible for digging up that other body of data, Facts. And facts need to be vigorously examined initially; often they too are assumptions once their pedigree is exposed. And a questionable fact needs a sensitivity analysis. The staff can do this without consulting the decision-maker where detail is concerned: engineering, costs, or other presumably quantifiable data. Next comes methodology or discussion. This is a job of the staff. Conclusions are independent of methodology unless your staff is inept, to phrase it kindly.

Leaving people, next comes the organization of the paper. The staff study and estimate of the situation have a prescribed format. It would be a major advance in operations research if OR study papers were organized so that the reader could find the facts, could find the assumptions, and could get some idea of the various sensitivities without redoing the study. Too often there is a statement of the problem, a discussion with facts, assumptions, and methodology inextricably mixed and undefined, no sensitivity analysis, and then conclusions. Such a paper does not breed confidence. Admittedly, assumptions occasionally influence methodology and these two become intertwined, but this is not the normal occurrence.

These brief comments should answer the question of: "What is operations research?" As one industrialist defined it: "Operations research is one of several staff tools to aid the manager in reaching a decision." He went on to say: "If you are going to get maximum advantage from the process, you (the manager) must become involved." Commander can be substituted for manager without altering the ideas expressed.

Next, who are the practitioners of operations research? These days their name is legion. I am not talking about military OR/SA specialists, I refer to the total community. Their journals are called Operations Research, Management Science, and Econometrica. They are primarily physical scientists, engineers, mathematicians, econometricians and statisticians. On the other hand, philosophic logic and Greek literature have been commended by certain outstanding practitioners as ideal academic preparation. The coursework currently given in American universities is heavily oriented toward certain kinds of mathematics and business administration. This

emphasis on methodology may obscure the overwhelming importance of the input. The philosophy major is less likely to forget this fact and will remember the precepts of Ecclesiastes, 1st Chapter, 15th Verse, "That which is crooked cannot be made straight; and that which is wanting cannot be numbered." Or as Sergeant Friday of Dragnet said repeatedly, "Give me the facts, Ma'am, just give me the facts." The statement of the problem, the facts, and the assumptions predetermine the conclusions. The methodology is an orderly discussion. If sufficiently mathematical and detailed, it will expose a fine grained structure in the conclusions. But the only way methodology can alter conclusions is to change good input to bad conclusions by misinterpretation.

Having scooped up the whole universe of practitioners, I'll try to narrow them down to the fraction apparent in the Army. This has two parts, a uniformed segment and a civilian segment. The civilian group is further subdivided into civil service and contractor personnel.

For the officer, there now is the OR/SA Officer Program. MOS 8700 is established to describe a class of assignments. The Summary and the first paragraph of Duties are worth reading:

"Summary: Conducts qualitative and quantitative analyses of complex military and military-related problems and studies by application of the analytical methodology of operations research/systems analysis (OR/SA). Identifies and clarifies major factors of the problems and studies, and as an aid in decision making, provides to the decision maker qualitative and quantitative bases for assessment, and the derivation therefrom of the relative desirability of various alternative choices.

"Duties: Employs the techniques of OR/SA such as analytical mathematical models, statistical analysis, network analysis, stochastic processes, queuing theory, servo theory, game theory, Monte Carlo techniques, and linear, non-linear, and dynamic programming for the solution of assigned problems and studies. Conducts detailed analytical studies and original analyses of complex military and military-related problems in highly significant, comprehensive, and often controversial areas of interest such as strategy and tactics, logistical systems, surveillance and target acquisition systems, weapon systems, resources utilization, force structures, manpower requirements, cost effectiveness, intelligence, management, engineering and technical, political, and economic developments."

Both paragraphs appall me. I was taught that the star of the general staff was defined by the summary definition except for the phrase "... by applications of the analytical methodology of operations research/systems analysis." The duties paragraph emphasizes the methodology aspect, by inference overlaps the logistical officer program, the ADPS officer program, and others; and makes one wonder if we are not going the route openly announced in some colleges of education: "You don't have to know what you

are teaching; all you need to know is how to teach." If you read to the end of the job description, some perspective returns as I will quote Qualifications and Examples of duty positions for which qualified:

"Qualifications: Must be able to perform duties described above and possess the following special qualifications:

"Must have academic background and/or experience equivalent to that obtained through post graduate study in operations research, systems analysis, mathematics, statistics, economics, logic, management, or in other fields related to OR/SA.

"Must have ability to direct OR/SA contracts, and to work with interdisciplinary groups.

"Should have comprehensive working knowledge of data processing methods and techniques, to include model building and linear programming.

"Must be able to communicate ideas effectively, both orally and in writing.

"Must have mature judgement and positive objectivity in the analysis of problems where controversial interests must be considered.

"Must have the faculty for orderly thinking conducive to analytical solutions of problems.

"Examples of duty positions for which qualified:

"Operations Research Officer
"Systems Analyst
"Staff Officer
"Project Officer
"Force Structure Analyst
"Operations Research Analyst"

I am not deprecating the requirement for officers trained in the methodologies cited. I would suggest they also know what they are manipulating. Manpower management is different from operating a tactical operations center, and both are different from spare parts supply. You can apply the techniques to all three. But an 8700 having successive assignments in such diverse operations would have trouble verifying his data banks.

Oddly enough, the Army Educational Requirements Board recognizes three kinds of training: Operations Research (Business); Operations Research (Engineering); and Systems Analysis. With one MOS I am not sure how you keep the educational products sorted out for use. Some such sorting seems desirable. There is a very real split between two of these types of background. The man with the physical science and engineering background has

faith in effectiveness indices; the product of the business administration route has faith in his costs and none in effectiveness figures. Both have blind faith more often than not. Engineering performance is not necessarily military effectiveness. Nor is a speculative tally of dollars a reflection of national costs, under mobilization conditions at least. With ACSFOR the protagonist for the OR/SA Specialist program, some of these personnel problems should be resolved in conjunction with DCSPER and OPO.

It may be more illuminating to see where the civilian component operates. DCSPER and OPO are supported by both in-house and contractor efforts. Policies are studied and operational personnel distribution systems are designed.

ACSI, DCSOPS, and other general staff sections obtain policy study support from contractors.

ACSFOR and the Combat Developments Command use in-house and contractor support in all phases of materiel and force development. Paralleling this pair are CRD and the R&D portion of the Army Materiel Command.

Move on in the materiel cycle and you find DCSLOG and the Army Materiel Command using both in-house and contractor support. Applications are many -- transportation, scheduling of overhaul, spare parts procurement and supply, depot operations, to name a few.

The Chief of Engineers has in-house groups.

USARV and Seventh Army have contractor support.

The Comptroller of the Army has his in-house capability. I'll not list the highly visible groups at very senior echelons. But one can see that practitioners of the techniques of OR are widespread throughout the Army system. Moreover, they are in short supply. This latter fact should suggest preferential attention to their use.

Considering the definition of operations research given earlier in the talk, how do you use the scarce talent? First, consider that quality of staff output is a function of time available to work. Overload the OR/SA people and you get degraded results. A priority system for studies is as important as an allocation system for major items of equipment in short supply. Under current conditions, not too facetiously, I would propose two classes of OR/SA effort in any command: One to respond regardless of quality, and the other to do well the work vital to the command. The latter effort will need some insulation from time pressures and free access to raw data. Remember that validation of data is an important part of any analysis. This leads to the desirability of the OR/SA group having within it people who have gathered some of the types of data being used. Very little data can be separated entirely from an understanding of the environment in which it was gathered.

staff man needs to consider if he is really doing a competent job or whether he is behaving as an artist entitled to support by a patron. The commander should consider whether he is giving honest guidance to the staff. When both have clear consciences, then the joint effort to resolve misunderstandings is worthwhile. Thus the real evaluation of an OR/SA effort is, "Was it used; and if not, why not?" Negative decisions reached are useful, resources are not infinite; but a mathematically elegant solution to the routing problem of the military tanker fleet wasn't of much use since the boundary condition that the ships touch at home ports periodically was omitted. Another founding father tells this on himself and also swears he will never again touch a practical problem.

Having gone through history, philosophy, operations, personnel, and review and analysis of operations research and systems analysis as currently found in the Army, it is time to summarize a personal viewpoint. The existence of this symposium and your presence at it prove that the Army recognizes the fact of OR/SA and also its importance to some degree. It is a technique for studying problems and it will not go away. Thus, the whole organization had better become comfortable with it and learn how and where it is appropriate to use the art. It is questionable if it is a science although it may use fractions of many hard and soft sciences.

"Deutsche Gesellschaft fuer Unternehmensforschung" is the name of the German Operations Research Society. "Unternehmensforschung", a coined word, roughly translates into "Undertaking Research" or "Understanding." Understanding can use the scientific method but is hardly science. It needs no sophistication at all. The Canadian National Railways (whose president was an OR practitioner) installed a course pitched to the academic level of every gang foreman. Every foreman went through it. As a result, many operating practices were improved by the application of observation, common sense, and imagination. The foremen started looking at their operations as problems, not practices. So I maintain we are talking about an action, a function, when we speak of OR!

This function manipulates or considers facts and assumptions. The study is the whole of the facts, assumptions, and manipulation. If the OR practitioner is to be a whole man, he must be as familiar with the scenario, the data, and the assumptions as with his matrices. Otherwise he can only be a fraction of an interdisciplinary team. In this complex age, there are very few whole men. The interdisciplinary team is more likely to turn out the valid studies. This fact is implicitly recognized throughout a good many parts of the CONUS establishment, certainly in the Army General Staff, the Army Materiel Command, and the Combat Developments Command.

The Army will probably not be comfortable with the notion of OR/SA, however, until it can rewrite the 8700 MOS to look more like a specialist or, rather, as the several specialists recognized by the Army Educational Requirements Board. It will be really comfortable when you find S-1/G-1, S-3/G-3, and S-4/G-4 listed as examples of duty positions for which the 8700 or his several successors, is qualified. There is no reason why this should not occur some day.

AN AUTOMATED FORCE PLANNING SYSTEM

Brigadier General Paul D. Phillips (Ret.)
Acting Deputy Assistant Secretary of the Army
for Manpower and Reserve Affairs

INTRODUCTION

Mr. Chairman, Gentlemen,

We are delighted to be here to discuss with you the subject of force planning.

This first slide (Slide 1 on) shows our schedule (Slide 1 off).

Whereas force planning is not new in the Army, having always been a G3 function, the heavy emphasis on it in the Army is new, stemming from the establishment of ACSFOR in 1963 through the establishment of large force planning analysis staffs in the Chief of Staff's immediate office in 1966 and 1967, to the creation of an Assistant Secretaryship now holds.

The new emphasis simply reflects the necessity of making force structure decisions right the first time in a world where potential Army missions are profuse, and where manpower and weapon systems are incredibly expensive. Complicating the decision-maker's problem are the great uncertainities which face him; uncertainities which range from enemy capabilities and intentions down to how many soldiers in a critical MOS are going to re-enlist.

So that we start on the same basis, here (Slide 2 on) in the absence of a definition in the Army Dictionary, is a definition of force planning on which we three, at least, have agreed.

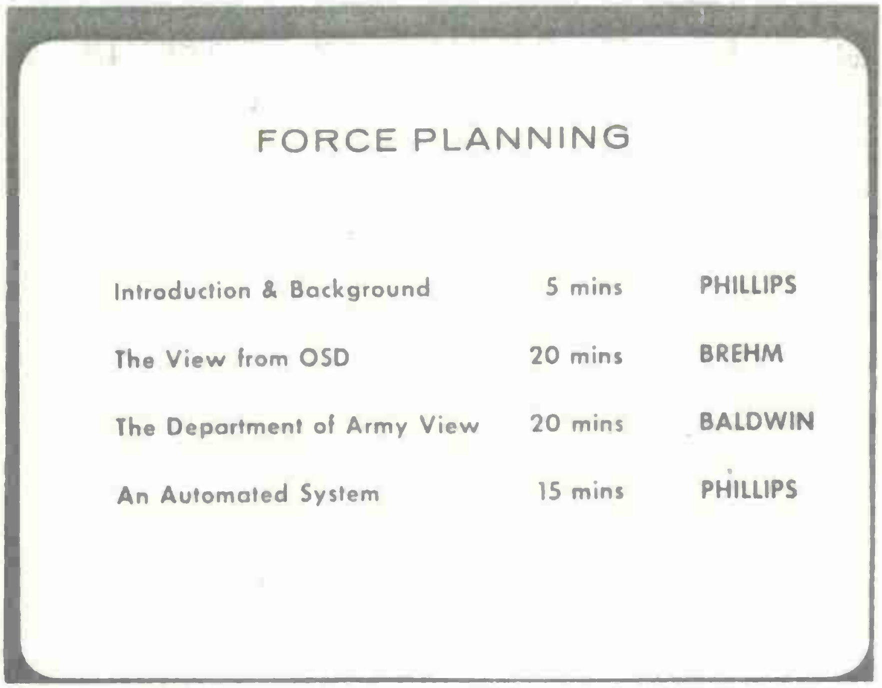
Finally, as part of the background for the discussion, I would like to explain the dynamics of force planning as depicted on this slide (Slide 3 on). As shown here, and admittedly this is a highly simplified portrayal of the system, the planning consists of five processes shown across the top and four forces, shown on the next line. The process beings with missions as determined from authoritative sources. In earlier times these were spelled out in National Security Council Memorandums. More recently they are derived by the JCS in a less formal manner. The JCS and services then, through a series of studies, analyses, and war games, and in a process here called estimation derive the objective force. This is the force which the JCS and services believe is required to carry out the mission.

Next, the systems analysis side of SECDEF's Office, introduces the economic and political aspects of life in analyzing the objective force to produce the approved force. This force is communicated to the services by SECDEF in a Draft Presidential Memorandum. There are a number of these. We are interested primarily in two: that for General Purpose Forces and that for Land Forces.

Next the SECDEF's budget people enter the process. Together with the service comptrollers and in a process called development, they introduce technical and budgetary aspects to produce the authorized force.

In a process called management, the services attempt to make the actual force the same as the authorized force and, except for human error and friction in the system, they do.

Employment of the actual force through plans - as we're doing in Vietnam provides a check (Slide 3 off).



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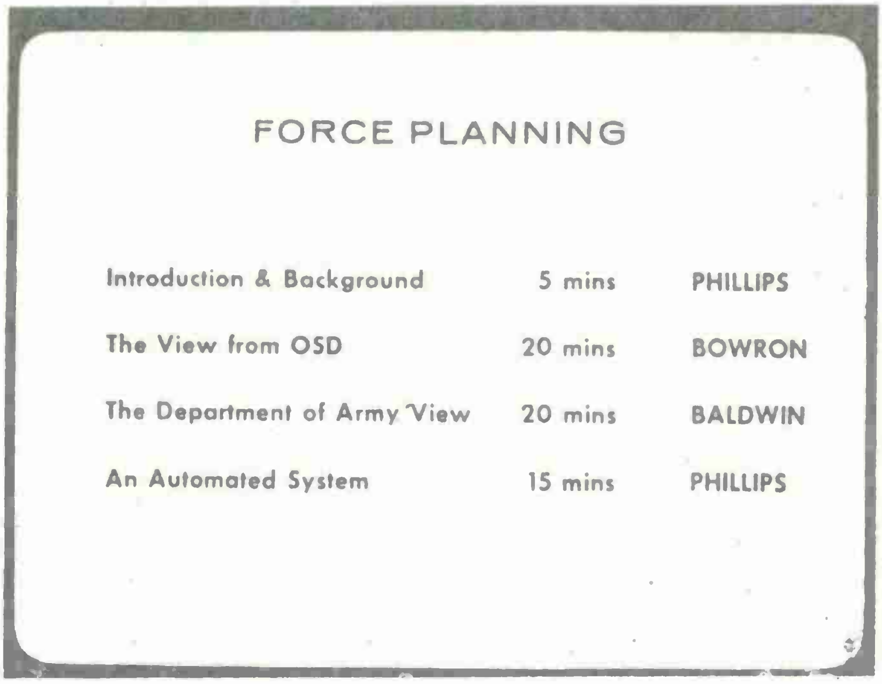

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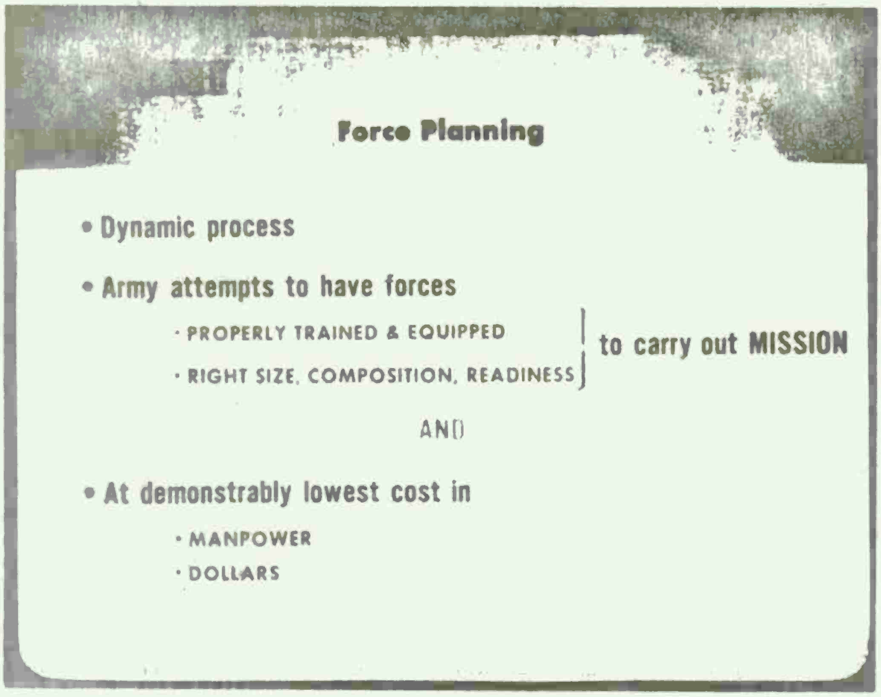

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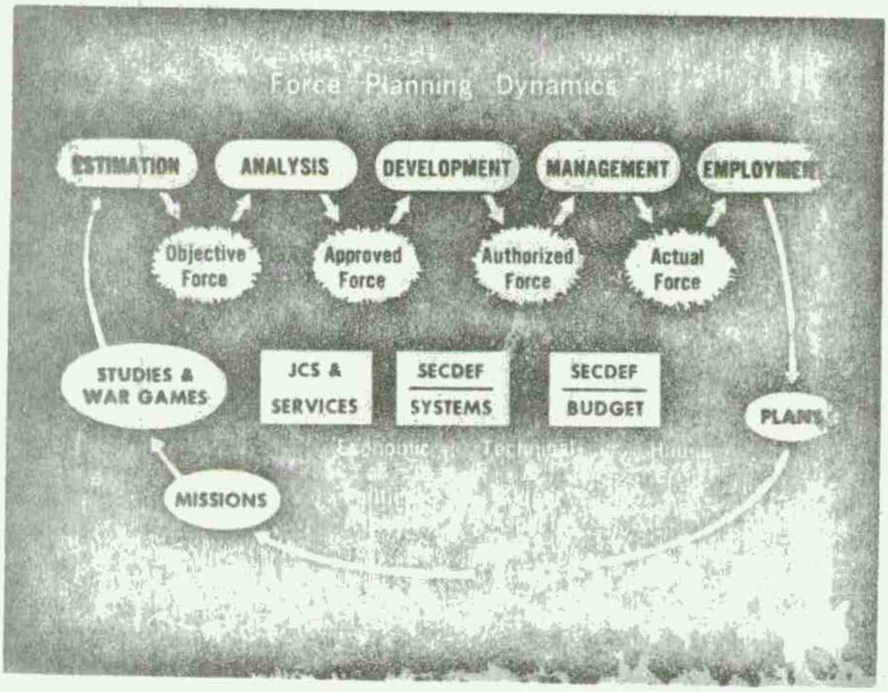


Slide 3

AN AUTOMATED FORCE PLANNING SYSTEM

Brigadier General Paul D. Phillips (Ret.)
Acting Deputy Assistant Secretary of the Army
for Manpower and Reserve Affairs

(Slide 1 on) - The Automated Force Planning System I will be discussing is being developed at Research Analysis Corporation under a Project called FOREWON (Slide 1 off).

An ideal force planning system must (Slide 2 on) operate in 3 modes, requirements, capabilities, and design. In the requirements mode, the mission to be performed is the input, forces required is the output, and resources are to be minimized. In the capabilities mode, the approved forces are the input and the degree to which the mission can be accomplished is the output. Since we would presume adequate resources would be made available for approved forces, they are not part of this problem. In the design mode, various levels of dollar and manpower resources are input and the force structure which will maximize accomplishment of the mission is the output (Slide 2 off).

Those parts of force planning covered by FOREWON are highlighted on this slide (Slide 3 on - flip down). We will be dealing with missions, with the Army, in studies and war games, and with the aim and hope of improving on the word "Estimation." We will be dealing with providing the decision-maker a set of objective forces from which to choose, which you will recognize is the output of the requirements mode. Finally, we will be dealing with the approved force, testing it against mission, which represents the capabilities mode (Slide 3 off).

The features which the model would seem to require are shown here (Slide 4 on). The model must be dynamic, that is, able to handle time-phased troop requirements; for without this feature, there is no way of handling readiness requirements, no way of apportioning the total force among active army and reserve components, and hence no way to determine peacetime costs.

The model must be able to handle major forces (divisions and brigades), roundout forces, logistics, strategic movement, and costs.

The model must have a fast cyclic rate. Here the aim must be to handle one alternative in not more than 24-hours; because the only advantage of an automated system is that it permits the decision-maker to examine many alternatives.

Finally, the model must be useful--useful now and for the future. This means, it must be helpful in solving the kinds of problems faced by the force planner and decision maker (Slide 4 off).

With this as background, let me show you how we put together a rudimentary force planning system using models which were developed over a long period of time for a variety of customers to help solve a wide range of problems (slide 5 on).

We started with the RAC Computerized Theater Level Quick Game which has four internal models as shown. Force resolution is the division or brigade; time resolution is one day. The output is time phased major combat force requirements, and their combat postures, by which is meant defending, fighting a meeting engagement, in reserve and the like; and a day-to-day trace of the FEBA (Slide 5 off).

Next, SIGMALOG, (Slide 6 on) a Theater Logistic Simulation was added, with the Building Block Model of Strategy Tactics Analysis Group incorporated in it. The Building Block Model provides time phased combat support and service support unit requirements to support the combat force; and SIGMALOG proper, using the two models shown, can compute time phased tonnage requirements and a peak force troop list by standard requirements code (Slide 6 off).

Next, ADROIT, (Slide 7 on) a Linear Programming Model for determining Sea and Airlift requirements, was added. Using time phased theater tonnage requirements from SIGMALOG and technical and cost data on candidate vehicles, ADROIT can design and cost a least-cost transportation fleet (slide 7 off).

Finally, two Cost Models (Slide 8 on) were added. The Dual-State Cost Model (the two states are peace and war) which accepts time phased deployments and produces the recurring costs of a force for both states and the non-recurring cost of going from one state to another. This model costs the world wide Army force structure.

The ISOC (Individual or System Organization) Cost Model which accepts the peak force in a given theater and computes the peacetime burden of owning such a force.

This then is what we call the Prototype System. We applied it last summer to seven alternative scenarios developed by the Army for Northeast and Southeast Asia. It has a number of shortcomings which are being corrected now. Since January, the General Staff has used an improved version of the prototype in this year's Army Force Development Plan (Slide 8 off).

You recognize, of course, that what I have described thus far is useful only for looking at a single theater. The force planner is interested in the whole Army structure. My next slide depicts a concept for determining the total combat force requirements to handle multiple contingencies (Slide 9 on).

Starting with mission, and here we are assuming that it is to be able to handle two major and one minor contingencies, we develop scenarios for whatever places these contingencies might occur. These are being developed now by the Engineer Special Study Group in a study called "SPECTRUM."

Using these, or any scenarios, and a theater force designer along the lines of the Quick Game and SIGMALOG Models of the prototype, we produce a force capable of doing whatever is desired on the ground in each of the contingency areas and the logistic requirements for each such force.

Next, the Army combines the various individual scenarios into composite contingencies, each one of which represents a feasible refinement and more specific statement of the very general starting mission. For example, composite contingency 1 might be, defend Europe on the Iron Curtain, maintain a foothold in Southeast Asia, and be prepared to react to a situation in South America with one brigade force.

Now we come to a very important point. We must agree that the ability to carry out all of the composite contingencies one at a time, in a set of composite contingencies which we have defined, represents satisfactory mission accomplishment.

We next design a force to carry out each of the composite contingencies. As you see, this is a simple combination of the theater forces previously determined. At the same time, we determine the strategic transportation requirements for each composite contingency. Now we have say 1 to M composite contingency forces and corresponding transportation requirements.

There remain two steps. We find the union of all elements of the composite contingency forces--and this we call Objective Force #1--and cost it, and we determine the least cost deployment fleet. In finding the union, we are determining the smallest force capable of handling all composite contingencies (CC) one at a time. For example, if CC_1 requires 4 infantry divisions by D+30 and 7 by D+90, whereas CC_2 requires 5 infantry divisions by D+30 and 6 by D+90, we must have 5 by D+30 and 7 by D+90 to be able to carry out both CC's one at a time.

You have probably already noted that the way alternative objective forces, transport fleets, and costs might be generated is simply to alter the elements making up the CC's. For example, if the enemy threat differs, or if one decides to hold at a different place in any one theater, a different objective force emerges. This, then, is a concept for broadening the theater force planning system into a world wide system (Slide 9 off).

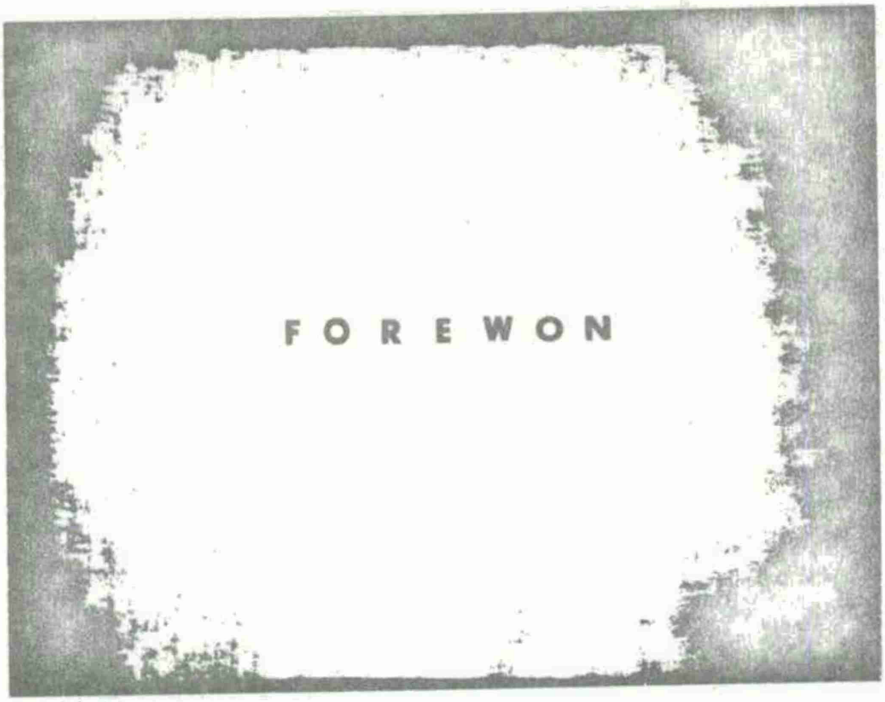
A similar concept exists for the capabilities mode which we will not have time to show.

However, I do want to give you an idea of the kind of output we will get from the system just described and the sort of things we could do with it. (Slide 10 on) Imagine that this is one objective force, that is, the union of all the units by type and time phasing required by one set of composite contingencies. We have units down the left column by SRC and time across the top. Numbers in the body of the chart are, therefore, time phased requirements. Now I want to determine what part of this objective force must be in the active Army, what in the reserves, and what unmanned. All I need is a set of rules which tells me the readiness dates of reserve and unmanned units by type. In the example here, reserve infantry divisions cannot be ready until D+40; therefore, the 6 required before D+40 must be in the active Army, but the 7th, 8th, and 9th can be reserve. And, since, the 10th, and 11th infantry divisions are not required until D+360, they can be unmanned units in peacetime. Similar cut-offs for all of about 600 SRC's will permit apportioning the force among active, reserve, and unmanned units. Schematically, the "Green" units are active, the "Orange" units are reserve, and the "Blue" units are unmanned (Slide 10 off). A refinement of this concept would permit examining the implications of variable manning levels for active Army units.

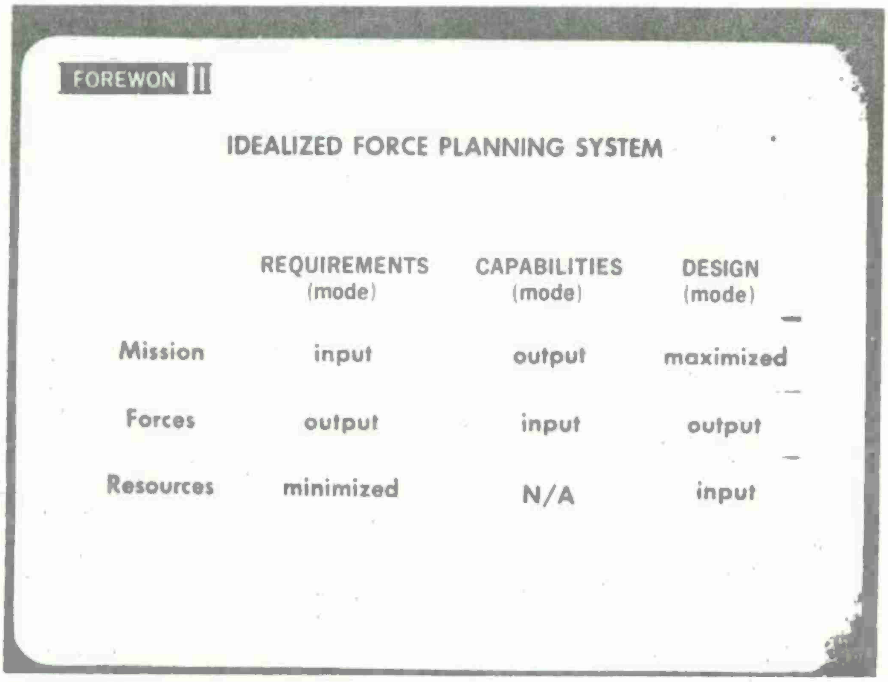
Finally, we see (Slide 11 on) the kind of decision matrix we can construct. This slide represents a summary of what can be looked at in any detail desired. For each of 1 to say 20 objective forces we have a brief description of the force, its capabilities on the ground, its initial investment and annual operating costs, its manpower requirements for active, reserve, and unmanned units, and the make-up and cost of its strategic deployment fleet. Comparisons, then, between and among alternative objective forces is made easy (Slide 11 off).

Gentlemen, this has been a hasty overview of the RAC concept of an automated force planning system, a tool we expect to be of use to Army force planners and decision makers by permitting them to examine a relatively large number of force alternatives.

We are now ready for your comments, questions, and discussion.



Slide 1



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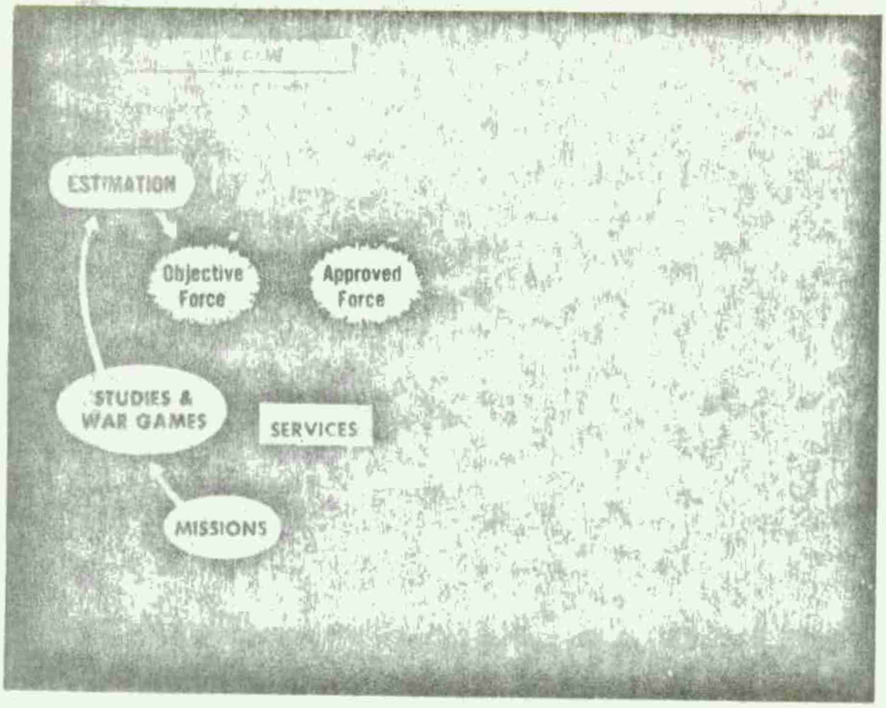

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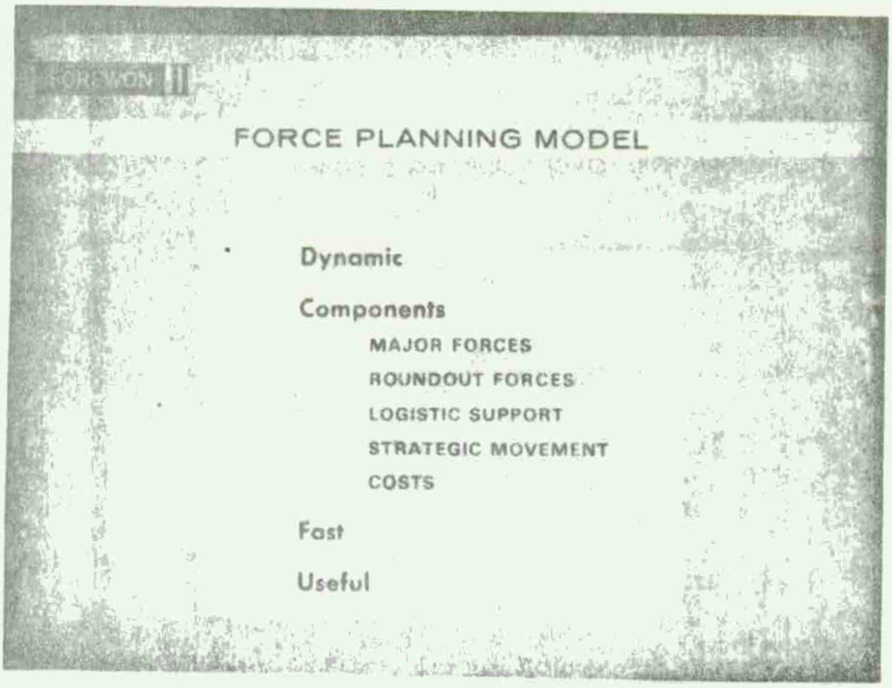

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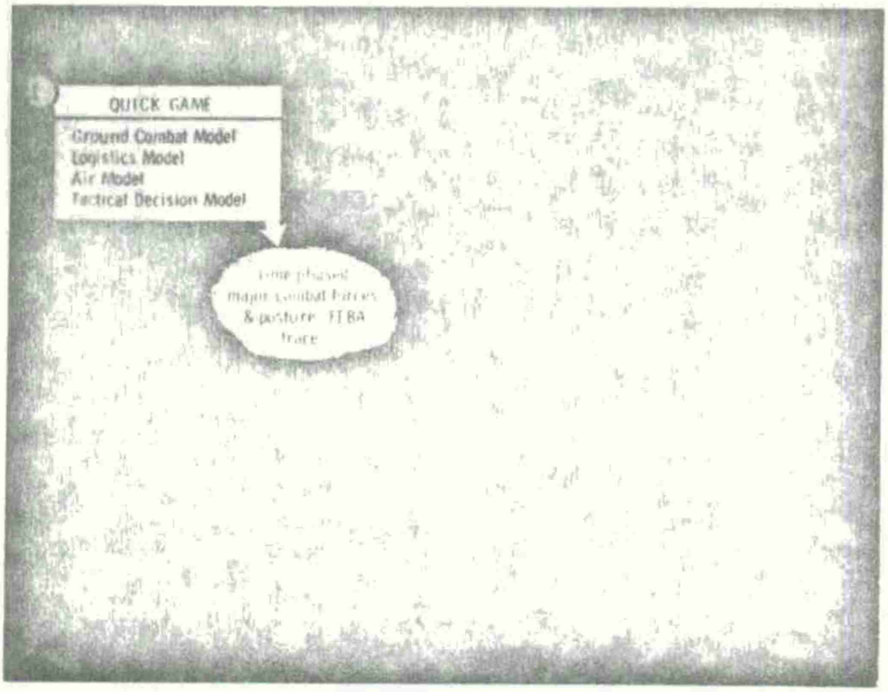

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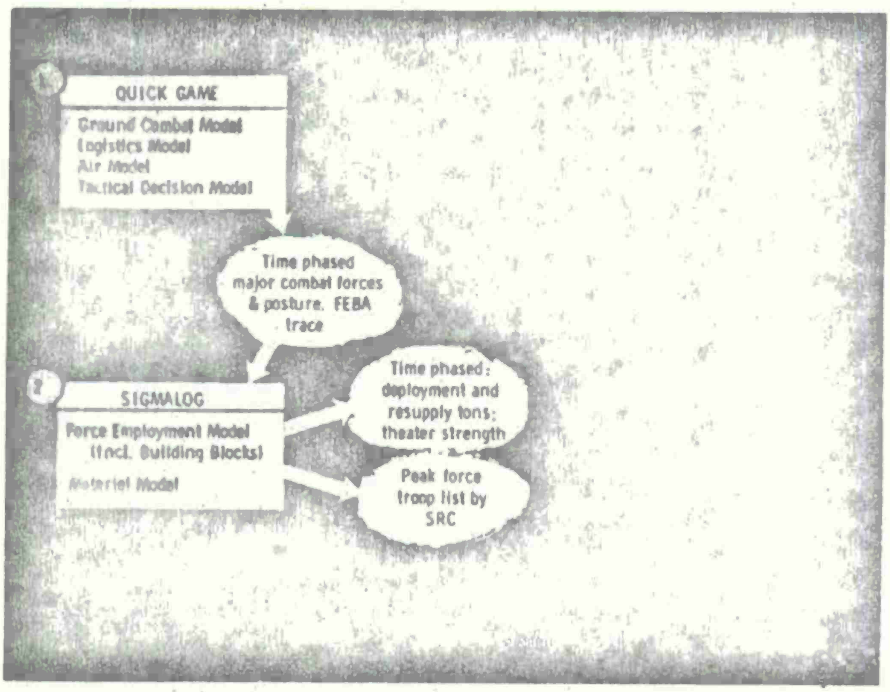

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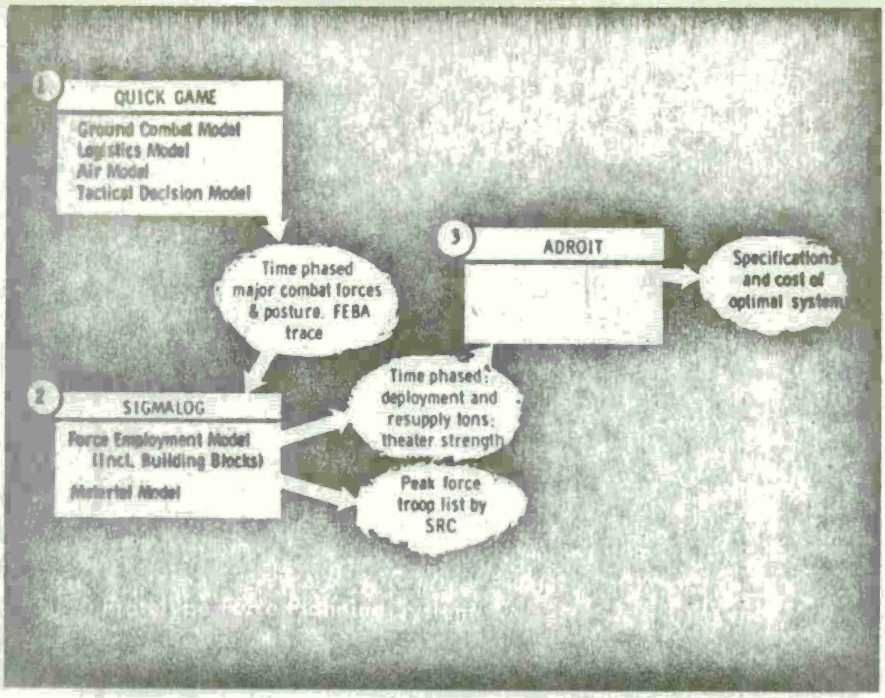

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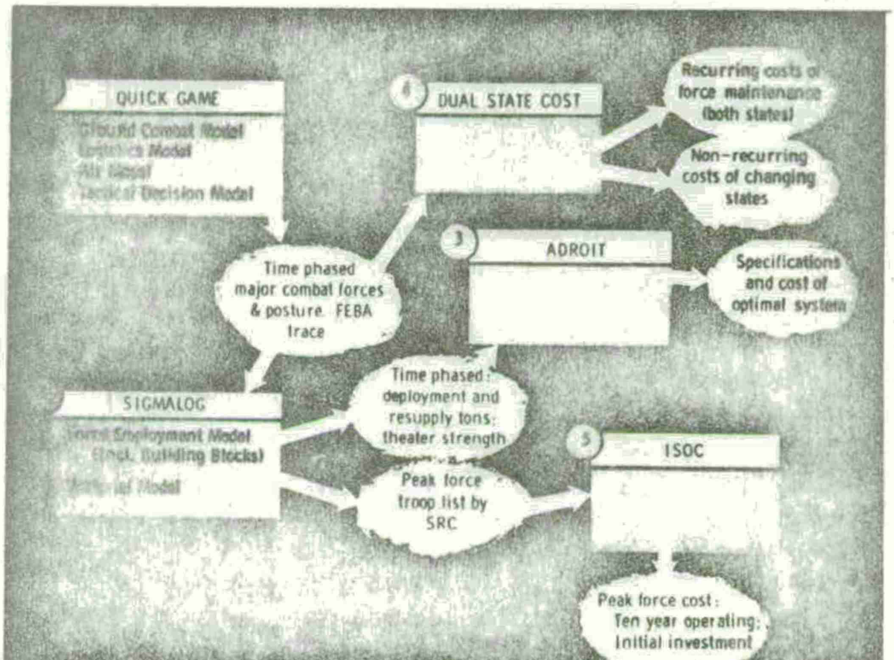

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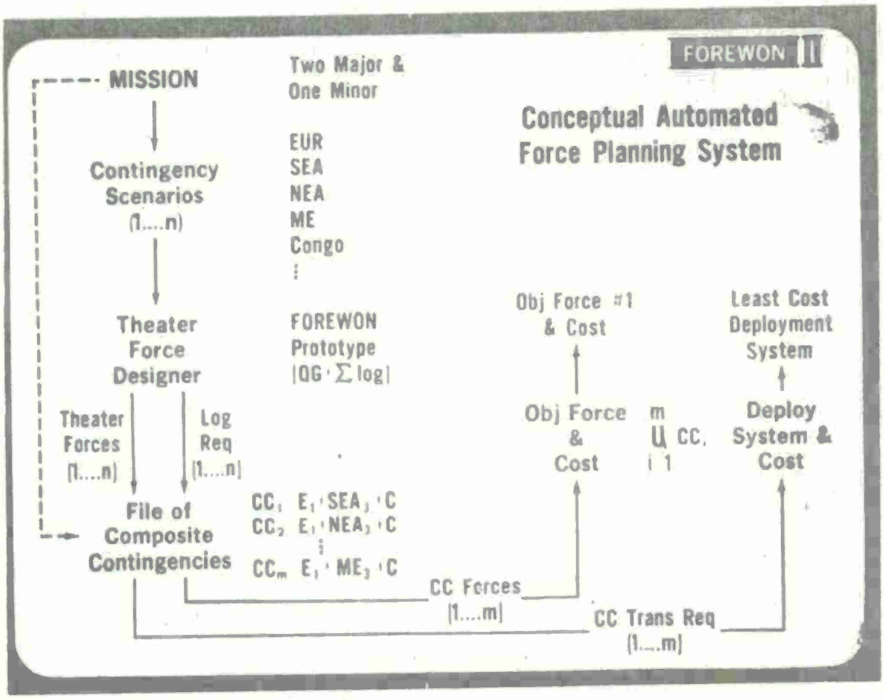

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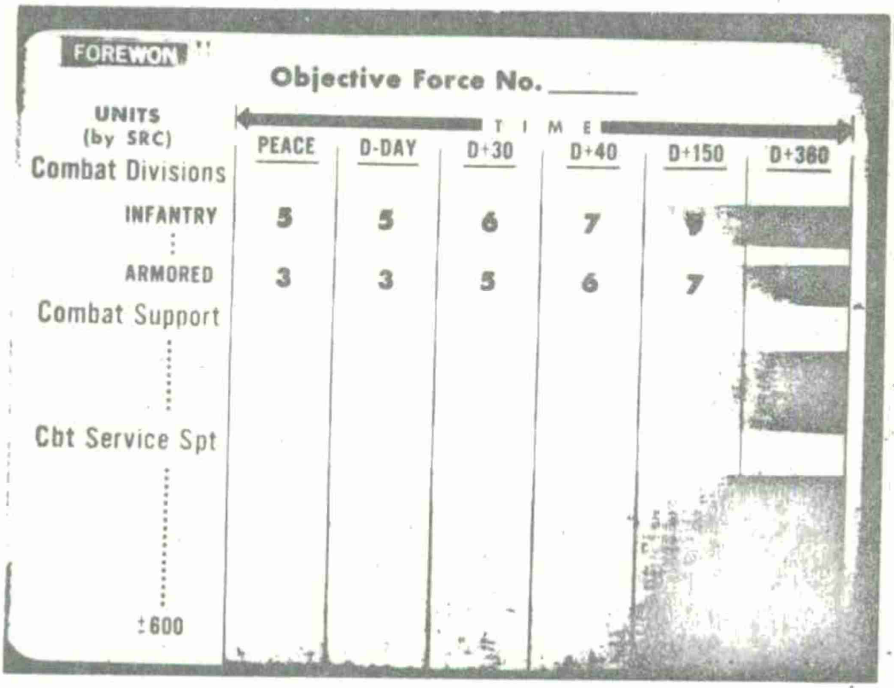
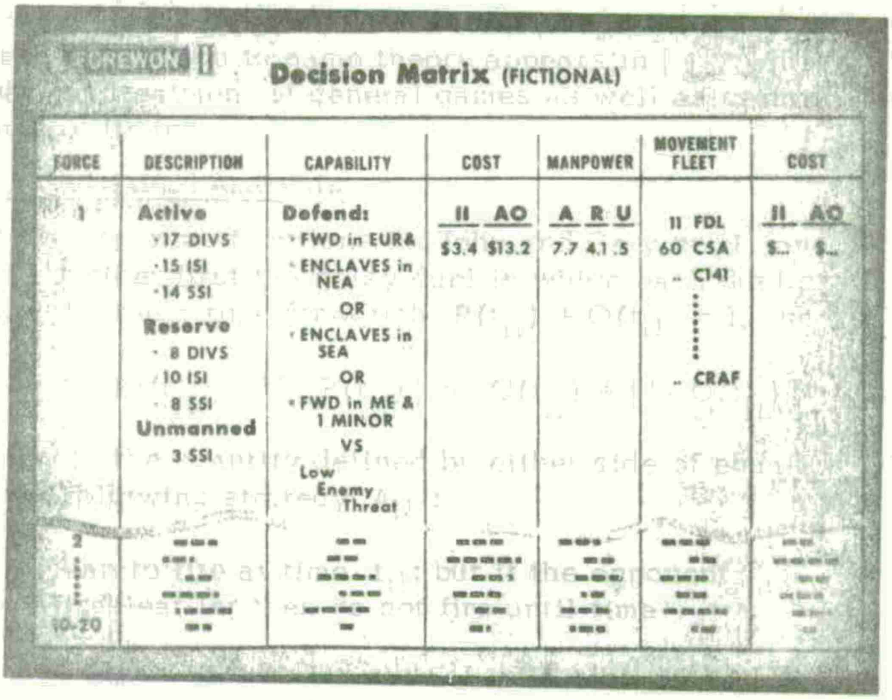


Slide 10


Decision Matrix (FICTIONAL)
FORCE
DESCRIPTION
CAPABILITY
COST
MANPOWER
MOVEMENT FLEET
COST
1
Active
17 DIVS
15 ISI
14 SSI
Reserve
8 DIVS
10 ISI
8 SSI
Unmanned
3 SSI
Defend:
FWD in EUR&
ENCLAVES in NEA
OR
ENCLAVES in SEA
OR
FWD in ME &
1 MINOR
VS
Low Enemy Threat
II AO
$3.4 $13.2
A R U
7.7 4.1 .5
11 FDL
60 CSA
C141
CRAF
II AO
2
10-20

Slide 11

STRATEGIES AND VALUES IN NOISY DUELS

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1. Noisy Duels

At high noon two gun slingers, Gary Cooper and John Wayne, stand at opposite ends of the main street in Laredo. The first duelist, Gary Cooper, has a gun loaded with m bullets (an m-shooter) while the second duelist, John Wayne, has an n-shooter. Slowly and steadily they advance toward one another with pistols drawn so that, if both live that long, they will eventually be face-to-face. Initially (corresponding to time $t = 0$) the duelists are far enough apart so that the probability of either hitting his opponent is zero, while when they are face-to-face (corresponding to time $t = 1$) the probability of hitting is of course 1. Either combatant can fire his shots at any times between $t = 0$ and $t = 1$ inclusive. If he fires too soon he might waste some shots when the probability of hitting is small; if he delays shooting, however, he risks being hit before he has an opportunity to fire. Our problem is to determine the "best" times for each duelist to fire his shots. The meaning of "best" is explained below.

At any time t, let $P(t)$ denote the probability that Gary Cooper will hit his opponent if he fires a shot at time t. Thus $P(t)$ is a function t, and will be called Gary's accuracy function. Similarly let $Q(t)$ denote John's accuracy functions. We assume that the accuracy functions are continuous and increasing and that each duelist knows how many bullets he and his opponent have to start out with as well as how accurate each duelist is. A duel is said to be noisy if each combatant hears his opponent's shots. Hence in a noisy duel, which we are considering here, each duelist knows at any time exactly how many bullets his opponent has left and can act accordingly. For example, if one duelist has no bullets left, then his opponent will not fire his last bullet until $t = 1$ when he is sure to hit.

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† On leave from Michigan State University

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In order to define what is meant by "best" shooting times, we must state what each duelist's stake in the matter is. Let us assume that a duelist wins one point if he is the sole survivor; he loses one point if his opponent is the sole survivor; he neither wins nor loses if both survive or if neither survives. (Since the duel terminates as soon as either duelist is hit, the only case in which neither survives is when both shoot and hit simultaneously.) By "best" shooting times we mean those which maximize a duelist's average or expected payoff assuming his opponent behaves rationally. This maximum expected payoff is called his value of the duel.

Analyzed mathematically, the noisy duel is a zero-sum two-person game. In reference [1] the present authors prove that this game has a value and discuss in detail the structure of reasonable strategies. We summarize our results and outline our methods in Section 2 below. A very elementary introduction to game theory appears in [4], while [3] contains a mathematical treatment of general games as well as certain duels and other games of timing.

2. The Mathematical Analysis

Let the accuracy functions for John and Gary be P and Q respectively and consider first the noisy duel in which each duelist has only one bullet. Let t_{11} be a time for which $P(t_{11}) + Q(t_{11}) = 1$, so that

$$(1) \qquad P(t_{11}) - [1-P(t_{11})] = -Q(t_{11}) + [1-Q(t_{11})] \ .$$

Let v_{11} denote the quantity defined by either side of equation (1) and consider the following strategy A_{11} :

> Plan to fire at time t_{11}; but if the opponent fires earlier then do not fire until time $t = 1$.

Suppose Gary follows strategy A_{11} . Let t denote John's planned firing time. If $t < t_{11}$, then with probability $Q(t)$ John will hit Gary, in which case Gary's payoff is -1, or with probability $1-Q(t)$ John will miss, in which case Gary will fire at time 1 and win 1. Hence if $t<t_{11}$, Gary's expected payoff is $-Q(t) + [1-Q(t)]$, which, since Q is an increasing function of time, is not less than the right side of equation (1). If $t > t_{11}$, then John will wait until time 1 if Gary misses at time t_{11} , so that Gary's expected payoff is $P(t_{11}) - [1-P(t_{11})]$, which equals the left side of (1). Furthermore, if $t = t_{11}$, then Gary's expected payoff is $P(t_{11})[1-Q(t_{11})] - Q(t_{11})[1-P(t_{11})]$, which equals v_{11} .

Hence we conclude that if Gary follows strategy A_{11} his expected payoff is never less than v_{11} no matter what John does. A symmetry

argument shows that if John follows strategy A_{11}, then Gary's expected payoff is never greater than v_{11} no matter what Gary does. Therefore, strategy A_{11} is an optimal strategy for both duelists and the value of the duel to Gary is v_{11} .

We now outline a recursive procedure for solving a noisy duel in which Gary and John have arbitrary numbers of bullets. Let t_{ij} denote the optimal firing time for the first bullet in the duel in which Gary has i bullets and John has j bullets and let v_{ij} denote the value to Gary of this duel. In order to solve the duel in which Gary has m bullets and John has n bullets, we assume that all "smaller" duels with the same pair of accuracy functions have been solved. In particular, we assume that t_{ij} and v_{ij} are known whenever $i \leq m$ and $j \leq n$ except when both $i = m$ and $j = n$. It can then be shown that there exists some $t = t_{mn}$ for which

$$P(t_{mn}) - [1 - P(t_{mn})]v_{m-1,n} = -Q(t_{mn}) + [1 - Q(t_{mn})]v_{m,n-1}$$

and that t_{mn} satisfies the inequality

$$t_{mn} < \min(t_{m-1,n}, t_{m,n-1}) \quad . \tag{2}$$

Consider the following strategy A_{mn} :

> If the opponent fires before time t_{mn}, follow a rational strategy in the resulting smaller duel. Otherwise, fire at time t_{mn} and then follow a rational strategy in the resulting smaller duel.

By "the resulting smaller duel" we mean the duel involving the numbers of bullets the duelists have left at any time. Inequality (2) implies that at time t_{mn} it will not be too late to follow a rational strategy in the resulting smaller duel, so that A_{mn} is well defined.

We can show, as was shown for the duel with 1 bullet for each duelist, that strategy A_{mn} works well against an opponent who fires his first bullet earlier than time t_{mn} and that A_{mn} works well against an opponent who fires his first bullet after time t_{mn} . Unlike the duel with 1 bullet each, however, it is not always true that A_{mn} works well against an opponent who fires his first bullet exactly at time t_{mn} . What usually happens is that simultaneous firing is advantageous to one of the duelists, but disadvantageous to the other. We say that t_{mn} is a <u>good first-shot time</u> for a duelist for whom A_{mn} is a rational strategy, namely one for whom simultaneous firing is not disadvantageous. A duelist for whom simultaneous firing is disadvantageous should follow strategy B_{mn} :

If the opponent fires and misses at time t_{mn}, then follow a rational strategy in the resulting smaller duel. If the opponent fails to fire at time t_{mn}, then select a time $\hat{t}_{mn}$ randomly (according to a continuous probability distribution) in a very short interval following time t_{mn} and fire at time $\hat{t}_{mn}$ (unless the opponent fires and misses earlier). Afterwards, follow a rational strategy in the resulting smaller duel.

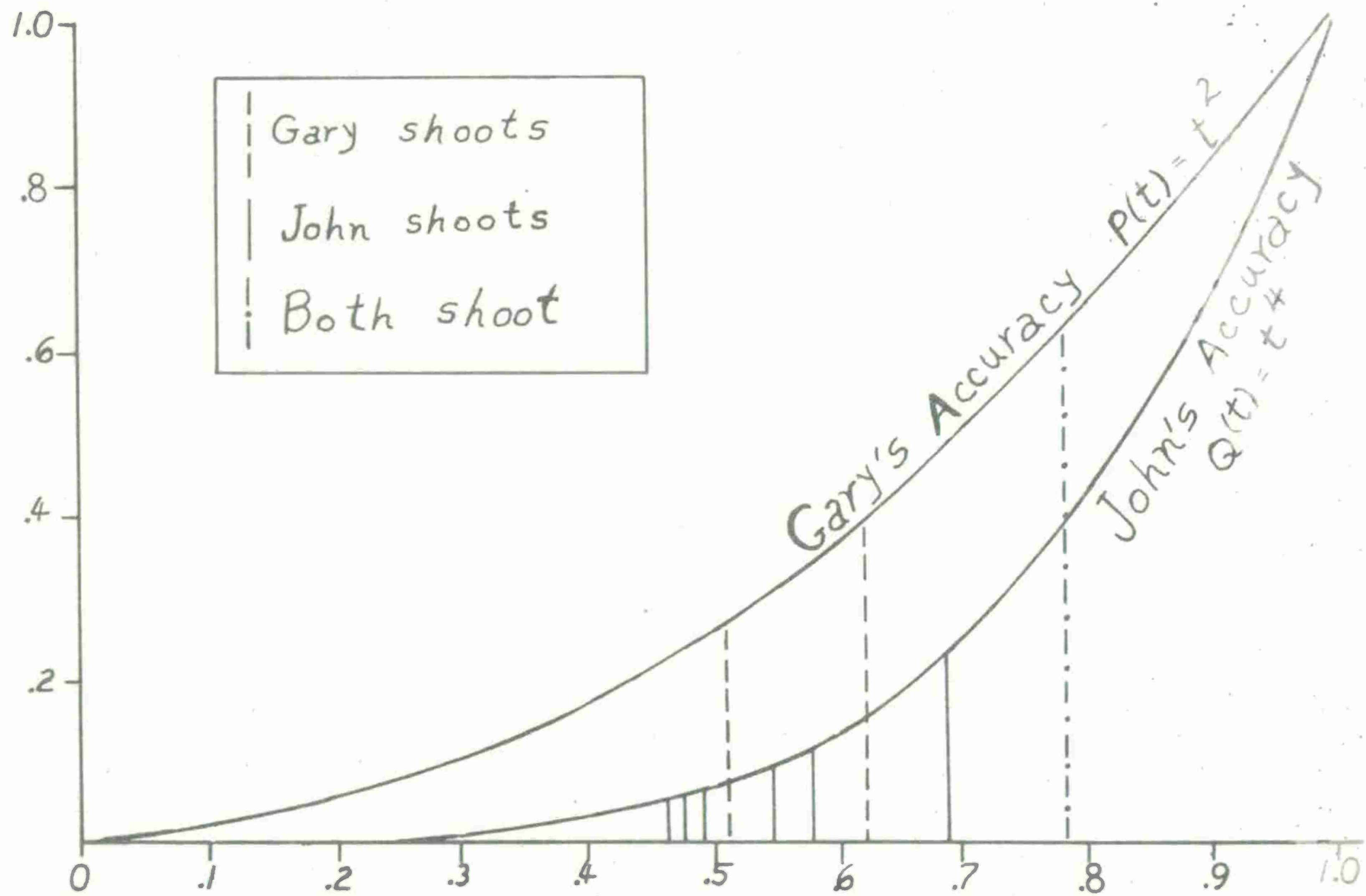
The mathematical relation which determines whether t_{mn} is a good first-shot time for Gary, for John, or for both is given in references [1] and [2].

3. An Example

Let us consider an example of a noisy duel. Gary has 3 bullets while John has 7 bullets. The accuracy function for Gary is $P(t) = t^2$, while for John it is $Q(t) = t^4$. Hence Gary is always (except for $t = 0$ and $t = 1$) more accurate than John, although John has more bullets. The course of the duel, assuming both duelists behave rationally, is represented by Figure 1. The solid lines indicate John's firing, the dotted lines indicate Gary's firing, and the line at time $t = .786$ represents the simultaneous firing of their last bullets. The abscissa of each line is the time at which a bullet is planned to be fired, while the length of a line represents the probability that the bullet if fired will hit the opponent. (Note that although we have indicated the firing times for all 10 bullets, it is quite likely that one duelist will be hit while he still has some bullets remaining.) The figure shows, for example, that John has a good first-shot time in this duel, but that Gary would have a good first-shot time in the resulting duel if John missed with his first 3 shots.

The value of this duel to Gary is computed to be 0.130. If in many repetitions of this duel both duelists (or their respective ghosts) behave rationally, then Gary will be the sole survivor 50.8% of the time, John will be the sole survivor 37.8% of the time, both will survive 5.7% of the time, and they both will be killed (as a result of their simultaneous firing of their last bullets) 5.7% of the time.

Tables of shooting times and values for some noisy duels as well as formulas for computing the value and shooting times for any noisy duel are found in [2].



The Progress of a Duel in which Gary has 3 bullets and John has 7 bullets.

Figure 1

4. The Price of Inaccuracy

A tabulation of best shooting times tells a duelist how to behave when faced with a given dueling situation. Another question we might raise is how best to prepare for a duel. (A more basic question which we won't discuss is how to have avoided the duel in the first place.) Clearly one should prepare for a duel by arming oneself with as accurate a weapon as possible and with as many bullets as possible. But suppose the weight of additional ammunition causes a decrease in accuracy, or suppose a fixed amount of money must be allocated between buying ammunition and taking shooting lessons. The problem of optimal preparation for battle is clearly an important but complex problem in military operations research. Perhaps the noisy duel can shed some light on one aspect of the problem.

The duel previously considered gave Gary a small advantage (since his value is positive) even though John has more than twice as many bullets. Clearly Gary's advantage is due to his superior accuracy. Computations show, in fact, that we would have to give John a total of 11 bullets versus the 3 for Gary in order to compensate him for Gary's superior accuracy.

Table 1 presents several examples of the price of inaccuracy. We fix the accuracy function of Gary to be $P(t) = t$. For a given number of bullets for Gary and several inferior accuracy functions $Q(t)$ for John, Table 1 shows the number of bullets John must have to overcome the effects of his inferior accuracy. For example, if $P(t) = t$, $Q(t) = t^2$, and Gary has 4 bullets, then John would need 17 bullets to overcome the effects of his inferior accuracy; if $P(t) = t$ and $Q(t) = t^4$, and Gary has 6 bullets, then John would need 1482 bullets.

For the noisy duel one conclusion seems clear: the price of inaccuracy is high and an enormous arsenal may be needed to overcome the effects of a decrease in accuracy.

Number of Bullets for Gary	John's Accuracy Function		
	$Q(t) = t^2$	$Q(t) = t^3$	$Q(t) = t^4$
1	2	3	5
2	6	13	32
3	11	34	122
4	17	72	335
5	25	130	754
6	35	215	1482
7	46	331	
8	59	482	
9	74		
10	90		
11	108		
12	128		
13	149		
14	172		
15	196		

Table 1 — The number of bullets John needs to overcome the effects of Gary's superior accuracy function $P(t) = t$.

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"PERSONNEL INVENTORY ANALYSIS"

by

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INTRODUCTION

The advent of "limited, small" wars, with the country officially at peace, has increased the rigors of Army mission accomplishment. Along with the simple mandate for all-out victory, gone are the virtually limitless supplies of money and manpower. Army management must work within the constraint of limited supplies, under close fiscal scrutiny, and in an environment which changes with relative frequency. Further, political considerations make manpower procurement a most delicate area. Consequently it is imperative that a means be devised for evaluating Army manpower requirements as accurately as possible; quantitatively, qualitatively, and timewise. The scope of this military management problem is enormous when one considers that Army manpower strength is approximately one and one-half million with an annual turnover of almost one-third that strength.

The initial requirement for efficient management is to determine within the framework of current plans and policies what the future demand for personnel will be and what future supply may be expected. If it appears that a shortage will develop, plans can be made to increase the supply or decrease the demand.

Army manpower requirements are generated by determining the number and types of military units needed to accomplish the Army's mission. The units then are translated into manpower requirements by branch/grade MOS for Officers; MOS for enlisted men; time; and, location. To compare these requirements to the expected future supply, present assets are projected to determine how many assets will be retained and the time period of this retention. Gains are projected by considering the possible output from the Army's training establishment, and the resulting projected assets are distributed by means of a simulation model to locations world-wide. Simultaneously, necessary draft calls are determined. The results are then analyzed to determine whether manpower requirements are filled to an acceptable level to permit the Army to accomplish its mission. This analysis is not only quantitative but qualitative as well; the level of training and experience of the force is taken into account. If the analysis uncovers future problems, plans and policies can be changed to solve them. For instance, training schedules or the size of the training establishment can be modified, as well as draft calls and distribution policies.

The type of analysis outlined is performed periodically by the US Army. When a contingency situation forces a change in the Army's mission a new plan must be devised and analyzed, even though the change may deal with only a segment of the total Army force. Naturally, quick response is desirable especially if problems discovered in analysis are to influence alternative plans. The Personnel Inventory Analysis System (P.I.A.) was designed for the purpose of providing this analysis quickly, accurately, and to a level of detail formerly impossible. The Personnel Inventory Analysis System was initiated at the Research Analysis Corporation (RAC) in July 1967, as a part of an ongoing effort sponsored by the Office of Personnel Operations (OPO), Department of the Army. Specifically, P.I.A. evolved from the RAC study conducted for the "Development of Techniques for Personnel Inventory Analysis." This study was initiated in September 1965, and is intended as a segment of the overall Army Personnel Management Information System.

Work performed on the P.I.A. System by the Economics and Costing Department of RAC resulted in the methodology reported in this document. The methodology has been employed in special applications for the current prime user, the Capabilities and Analysis Division, Office of the Deputy Chief of Staff for Personnel, Department of Army, with demonstrated success.

The P.I.A. System provides Army planners with a means of analyzing the manpower implications of proposed Army plans and will serve as a central part of the proposed Army Personnel Management Information System. A unique and versatile tool for Army manpower management, the system is of particular use in the solving of problems peculiar to the management and control of a large personnel force. While a multiplicity of applications are envisioned for P.I.A. only one application of the RAC developed methodology is reported in detail here. The application is concerned with personnel requirements for a proposed military force structure.

Under current Army planning procedures a mission is decided and a force structure for the mission is generated. The force structure lists the Army units, with implicit materiel and personnel requirements necessary for mission accomplishment. Army manpower managers must determine if the personnel requirements of a proposed force structure can, in fact, be met with present programmed assets. If it is found that requirements cannot be filled to a satisfactory level, alternative manpower plans and policies must be devised that offer solutions to the problems.

How the P.I.A. System aids in the procedures designed to ascertain and ensure an adequate personnel inventory is shown in Fig 1. First, the stated Army mission implies the number and location of required units and specifies the time frame for unit deployment. This information is combined to form materiel and manpower requirements dimensioned by time and place. The automated P.I.A. System then accepts and uses this information in conjunction with a data base of current Army records, rates, and policies. Four reports (data outputs) are produced, i.e., the projected assets report; the projected unit deployment report; the unit capability to meet goals

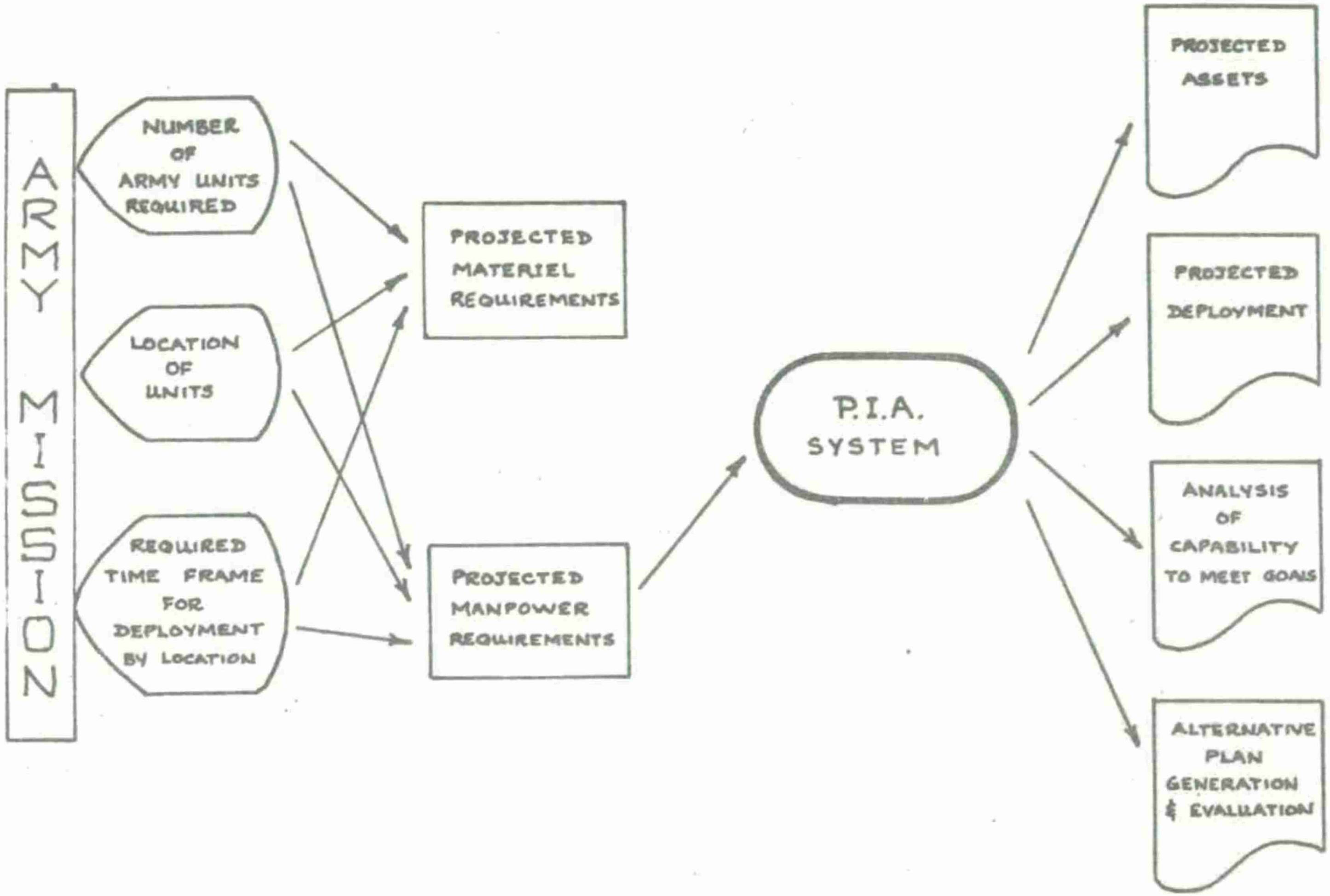


Fig. 1—P.I.A. in Capability Analysis

report; and, the alternative plan generation and evaluation report. In this manner the manpower manager quickly receives detailed information for an entire Army or any segment thereof. In Army management this entire procedure is called a "Capability and Analysis Study."

In a capability and analysis study personnel requirements of the force structure are analyzed in light of the projected personnel status and policies. Reenlistment rules, promotion rules, draft calls, and other relevant factors affecting the future force are considered. With the advent of P.I.A., capability and analysis studies have undergone significant improvement. The procedure is accomplished with greater speed, and depth of detail, accuracy, and scope than was heretofore possible. Past analyses, based on manually generated data, were time consuming in the extreme. These analyses were inaccurate and lacking in detail owing to the huge volume of complex data. Further, the two-month minimum "turn around" time allocated for the analyses function precluded any look at alternative plans. Feedback from plan evaluation to plan regeneration was prevented.

OBJECTIVES

The primary objective of the P.I.A. System was the development of a methodology for incorporation in a comprehensive, automated system to permit rapid analysis of force structure plans from both the qualitative and quantitative personnel aspects. The results desired of this and other study objectives is a computer analysis system having the capability of considering planning changes and the capability of projecting the degree of plan modifications that require a reaction by personnel.

Manpower computer models were to be developed and the data base necessary to compute and evaluate rates essential to manpower/personnel projections were to be established.

The study objectives were scheduled for accomplishment within the time frame allocated the four major project phases. In Phase I a series of integrated models were to be developed. These models were to start with the personnel inventory existing at a known point in time and project the status of that inventory for a two-year period. The asset projection, considering all sources of loss and gains, was to stratify personnel by branch/grade and/or MOS as appropriate and display the inventory status each month over the projection period.

In Phase II the distribution models were to be developed with the capability of using the output from Phase I as input. In addition the distribution system is to be capable of employing force structure personnel requirements as input, and allocating the personnel inventory to the various commands/groupings of the requirements in accordance with a prescribed schedule of priorities. In Phase II sufficient flexibility is required to permit distribution of personnel assets to the requirements of any force structure, assuming the force structure is adequately specific by branch/grade and MOS totals.

The results of Phases I and II are to be used for staff analysis as needed.

In Phase III a computer system is to be developed that will aid the analyst in flagging deficits and overages in various skill categories. Also the computer system is to be able to make suitable substitutions according to programmed routines and display alternative solutions to the problem areas both in quantities and in time.

In Phase IV the concept is to be able to employ the system derived in Phases I through III as a simulation model to derive quantifiable predictions of the personnel impacts of various policy decisions. Such policies as expansion of the training base, new additions to force structures, and changing Army end strengths are to be evaluated in part according to the effect of these factors on the personnel system. In addition, the P.I.A. System is to be integrated with other developing computer models as needed.

THE SYSTEM

The P.I.A. System utilizes a series of computerized models. A great part of the input data are drawn directly from current Army records, recorded on electronic processing media, and can be "fed" directly to the P.I.A. System. Some data such as personnel reenlistment and retirement rates, are not presently stored in the Army's data banks. In such cases data are acquired from various Army Agencies. The data then are keypunched and fed to the System. Specifications for automating the development of these data have been written. It is hoped that eventually all necessary data will be available in Army personnel data banks.

Policies affecting personnel are a variable input to the P.I.A. System and are controlled by the user. Printed forms for use in recording personnel policies are available to the user. System control cards may be punched directly from these forms. Some of the policies subject to variation are: training MOS priority; the training capacity of the MOS; officer retirement policies; enlisted personnel career flow; command priorities for personnel fill (worldwide); and, the minimum acceptable levels of fill. The list of variable policies is rather long but not all policies required as input need be changed for each operation of the system.

For use as a capability and analysis tool, as described above, the P.I.A. System will be run periodically, perhaps quarterly, for the entire Army. The System may be run occasionally for contingency plan revisions that affect only a part of the Army, as for instance any change in one or several MOS categories.

The P.I.A. System is modular to accommodate uses other than capability and analysis studies. The need for a personnel force projection or distribution simulation can be satisfied by simply running the appropriate module of the P.I.A. System. Modules can be classified as personnel inventory projections, simulated projected distributions of personnel, analysis and evaluation of projections and distributions, and as the generation of

alternatives (solutions to problems uncovered). The projection and distribution modules are described in detail in this paper. These modules have been completed and are now being used by the Army. Users, other than the Capability and Analysis Division of DCSPER, include the Enlisted Personnel Directorate of OPO for projected training requirements; the Director of Installations, Deputy Chief of Staff for Logistics, for the Stationing Capability System; the Army Behavioral Science Research Laboratory for the Simulation Model of Personnel Operations (SIMPO); the Officer Personnel Directorate of OPO for the Computer Assisted Assignment of Personnel (CAAP II); and the US Army Management System Support Agency for the Contingency Readiness System (CONREDS). In the last three cases, modules of P.I.A. have actually been incorporated in the systems.

The analysis and alternative plan modules are in various stages of development and are described only as plans. When the entire System is operational the manpower manager will be able to identify problems and propose alternative plans as solutions in a matter of several days for the entire Army. When only segments of the Army are under consideration, results will be possible in hours or minutes depending on the size of the segment and the complexity of the situation.

There are plans for two major revisions to the now operational portions of the P.I.A. System.

1. The consideration of "deployability" policy constraints in personnel distribution (i.e., not everyone is available to be sent on any tour of duty) and,

2. the inclusion of Warrant Officer personnel data.

Both modifications will enhance the System but will not change those portions now in existence.

Although the P.I.A. System was designed specifically to perform the capability and analysis function, the System has found use in other areas. As more Army Agencies become aware of the System and its capabilities, calls for System application increase with a frequency proportionate to potential user knowledge and awareness of the System.

Certain other systems that interact with the P.I.A. System are shown in Fig 2. The form of interaction also is depicted.

Four comprehensive reports are produced by the P.I.A. System. Each report furnishes data essential to the manpower management function.

The following reports are produced:

1. An asset projection, providing the manager with a representation of the manpower inventory under the new plan.

2. A projected asset distribution, providing the manager with figures that state the numbers of men that will be available to Commands receiving activated units.

Contributing Systems	PERSONNEL INVENTORY ANALYSIS SYSTEM	Receiving Systems
Trend Evaluator System	Historical / Projected } Rates	
	Gross Projected Training Requirements	Stationing Capability System
	Officer Inventory Projection and Distribution Modules	Computer Assisted Assignment of Personnel II (CAAP II)
Programming Quota System	Short Term Army Training Schedules	
	Manpower Inventory Projection and Distribution Modules	Contingency Readiness System (CONREDS)
MOS Data Bank	MOS Task Descriptions	
		Cost Factors System (COFACTS)
	Projected Training Requirements Modified by Accessions	Army "WHITE BOOK" for Army School Schedules

Fig. 2—Personnel System Interacting with P.I.A.

3. An analysis of the data (of items 1 and 2 above). This analysis identifies problem areas and ranks the areas in order of criticality.

4. An evaluation of the capability of meeting the goals of the plan, and possible alternatives that could be used as a means of goal achievement.

The four data output reports are analyzed by Army Staff Members at the policy making level where decisions are made and alternative plans devised.

DATA DEVELOPMENT

The P.I.A. System data development phase consists of a series of computer models now complete and operational.

In this phase, data necessary for subsequent phases is developed. Two reports are produced. One report presents the asset projections; the second furnishes the projected asset distribution.

The Enlisted Force Inventory Projection (an asset projection)

A report of the enlisted-force inventory projection for military occupational specialty (MOS) 17B2, Field Artillery Radar Crewman is an actual example of an output of this projection model. Figure 3 is an excerpt of the report. This Enlisted Force Inventory Projection is for two years, by month, covering the period from 1 July 1967 to 30 June 1969. The actual monthly figures and yearly totals are shown beneath the graph of this report. The values on the y-axis range from the minimum to the maximum values of the numbers graphed.

At the beginning of the period 17B2 is over-manned by 15 percent and 2 months later by 11 percent. However, because of the activation of new units in December 1967 the authorization suddenly climbs. Since the downward trend in inventory continues, the rate of availability drops to 85 percent. This rate figure appears in the report only if the difference between inventory and authorization is at least 10 percent.

The second page of this report (see Fig 4) describes the most important projected gains and losses affecting the inventory of the MOS.

The projection algorithm producing this report is essentially deterministic. The probability of a man's remaining in the service for the duration of the projection period is calculated based on historical rates that vary by a 4-character MOS, the Army component, and the individual's length of service. Every enlisted man's active Army record is reviewed. On the month during which an ETS or retirement is due the inventory is decremented by the probability of an enlisted man leaving the Army.

Future casualty losses by MOS are calculated by a combination of historical data and total-Army-casualty predictions. The historical data is used to determine what percent of the projected total Army casualties will fall to each 4-character MOS. Only casualties which are a total loss to the Army, i.e., those killed in action (KIA) and 40 percent of seriously wounded, are considered. A normal monthly attrition loss is subtracted which is measured as a percent of the average monthly inventory. This rate is either based on historical data that can vary by MOS or is one-half percent.

The monthly inventory is increased or decreased by a percent of inventory known as a seepage factor. Seepage factor is a term used to designate the uncontrollable and patternless flow of personnel from the less favored to the more popular MOS categories.

TWO YEAR INVENTORY PROJECTION BY MOS (7/67 - 6/69)

MOS. 1732

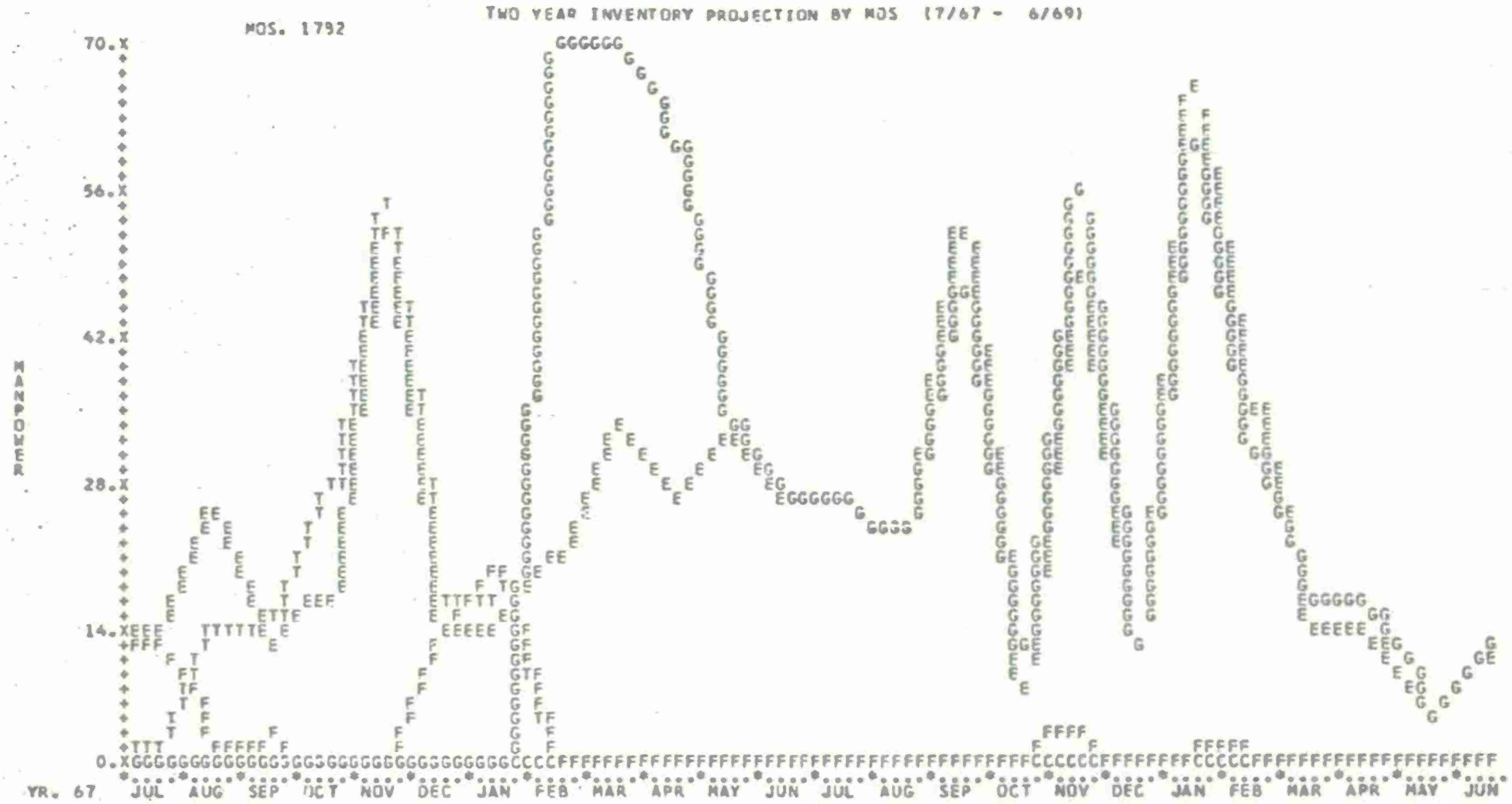
	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
AUTHORIZATION												
1ST YR.	608.	608.	609.	609.	609.	669.	746.	748.	748.	748.	750.	750.
2ND YR.	750.	750.	750.	750.	760.	760.	760.	760.	760.	760.	760.	760.
INVENTORY												
1ST YR.	698.	682.	673.	677.	674.	656.	634.	681.	716.	748.	750.	750.
2ND YR.	750.	750.	750.	750.	760.	760.	760.	760.	760.	760.	760.	760.

KEY TO SYMBOLS
A - AUTHORIZATION
* - INVENTORY INCL ALL GAINS + LOSSES

* TOTALS	BEGINING INV.	TRAINING GAINS SCHEDULED	TRAINING GAINS COMPUTER GEN	ETS LOSS	CASUALTIES	RETIREMENT	FOR LOSS	TPS	RATES TPS/FILL
1ST YR	727	155	262	301	12	0	69	161	18.13
2ND YR		0	332	324	12	1	23		-0.

OJT OPTION USED FOR THIS MOS (OJT WITH SCHOOL OR PCNT FILL)

Fig. 3—Inventory Projection by MOS (July 1967-June 1969)



	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
SCHEDULED TRNG												
1ST YR.	3.	15.	16.	29.	56.	17.	19.	0.	0.	0.	0.	0.
2ND YR.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
CASUALTY LOSS												
1ST YR.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.
2ND YR.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.
FEEDER LOSS												
1ST YR.	14.	3.	5.	1.	2.	15.	20.	1.	2.	2.	1.	1.
2ND YR.	2.	1.	1.	1.	5.	1.	4.	0.	2.	2.	0.	2.
ETS LOSS												
1ST YR.	15.	26.	14.	18.	53.	15.	16.	22.	34.	28.	33.	27.
2ND YR.	28.	25.	52.	9.	48.	13.	66.	35.	15.	14.	7.	12.
CMPT GEN SCH TRNG												
1ST YR.	0.	0.	0.	0.	0.	0.	0.	70.	70.	61.	34.	27.
2ND YR.	28.	25.	47.	13.	57.	14.	61.	31.	17.	16.	7.	14.

KEY TO SYMBOLS
T - SCHEDULED TRAINING OUTPUT
C - CASUALTY LOSS
F - FEEDER LOSS
E - ETS LOSS
G - COMPUTER GEN SCHOOL TRAINING OUTPUT

Fig 4—Computer-Generated Training, Gains and Losses MOS 17B2, (Jul 67-Jun 69)

The factors responsible for the transfer of an enlisted man from one MOS to another are numerous. Such transfers occur at random and without clear cut explanation, be the transfer one requested by the soldier; one accomplished for the convenience of the Service; or, one resulting from a curious concurrence of circumstances. The facts of life are that certain MOS categories attract personnel while other categories in effect lose enlisted men. The amount of gain and loss to an MOS can be predicted based on historical findings, but the flow between any two MOSs varies unpredictably. The net change to the total Army inventory resulting from seepage should be zero, but the effect on an individual MOS can be significant.

For selected MOSs a monthly loss to Officer Candidate School (OCS) is subtracted.

Feeder loss refers to men leaving one MOS and moving to another according to programmed career patterns. On-the-job training (OJT) or formal Army school-training, (both scheduled and computer generated) account for such movement. Computer generated training is governed by requirements in the receiving MOS, availability within the losing MOS, and Army career patterns. (Army career patterns are networks of paths connecting MOSs along which an enlisted man is moved as his career in the Army progresses.) The system user has the option to control this flow by restricting movement to or from any MOS, by eliminating this movement entirely, or by specifying a desired percent of fill other than 100 percent for any MOS.

Scheduled training refers to formal or on-the-job training (OJT) that is scheduled during the early part of the projection period and cannot be changed. The system begins generating training requirements at a point when changes to the training schedule are possible. As shown in Figs 3 and 4, although the inventory fell below authorization early in December 1967, training-output requirements did not begin until February when rescheduling results were possible. Throughout February and March, training output was at the maximum monthly training capacity of 70 men for MOS 17B2. For the remainder of the period just enough training output was generated to keep the inventory at the level of authorization. Training output then generally coincides with fluctuations in losses. All training referred to in this report is in numbers of graduates awarded the MOS.

Under yearly totals are values for beginning inventory, which includes operational assets at the beginning of the period; scheduled and computer generated training gains (formal or on-the-job training prescribed by the MOS criteria); Expiration of Term of Service (ETS) losses; casualties; retirements; feeder losses; the inventory of transients, patients, and students at the beginning of the period; and, rates. Personnel in a transients, patients, and students (TPS) status are nonoperational assets and not, therefore, included in the beginning inventory figure. A TPS rate calculation is based on the number of men in TPS status on the Enlisted Master Tape Record (EMTR) at the beginning of the projection period. This rate, modified by seasonal fluctuations, is applied as a draw-down on the inventory throughout the period with the result that the inventory figures reflect operational

assets only. Authorizations also refer only to operational strength, making a comparison meaningful. In generating training requirements, TPS fill is taken into consideration. In other words, to reach an operational level more men must be trained than are called for in operational strength requirements.

The second entry under "rates" represents an optional rate of fill that the user may specify at any value from 0 to 900 percent. This number affects computer generated training. The rate is applied to authorized strength, producing a required strength figure the model attempts to meet by moving men into the MOS. In addition, only strength in excess of this figure will be fed forward to any other MOS. If rate of fill is not specified, an attempt will be made to meet authorizations at 100 percent. However, men will be fed forward from the MOS as long as the inventory does not fall below the rate of fill of the prior month.

All entry level (apprentice)MOS's are entered from MOS 09B0 (trainees). A minimum number of men is specified below which 09B0 inventory cannot fall. If 09B0 strength is insufficient to feed the necessary training requirements of the proposed force structure, assets are allocated to the entry level MOS on a priority basis. There are four priority levels specified on the Priority of Input into Training (PIT) list. The system user having designated the highest priority entry level, then can specify minimum rates of fill for the three lower priorities. If entry level training cannot be met under specified constraints the user has several options: priority rates or the minimum required 09B0 fill may be changed; a request may be made that the best training possible under the circumstances be generated; or, the user may specify the training go forward disregarding draw-down on 09B0. With the latter two options a report of additional 09B0 requirements by month is produced.

For an MOS awarded only through formal training a report is generated that contains projected formal-training requirements, as shown in Fig 5. As mentioned earlier, the system calculates the number of formal-training graduates necessary to bring each MOS up to required strength. These graduation requirements (by MOS) are simply phased back by the course length and increased by a factor to account for failures-in-training and other anticipated, normal attrition, to achieve the school-input requirement.

Figure 5 shows the report for MOS 17B2, which is an entry-level MOS. The shape of the curve looks very much like that of training output shown in Fig 4. However, the steep increase occurs during the last week of October 1967 and the first week in November 1967 rather than during February 1968. The course takes nine weeks. Since the projection begins 1 July 1967, rescheduling of training is possible by 1 November 1967.

A concise description of this module appears in Appendix A.

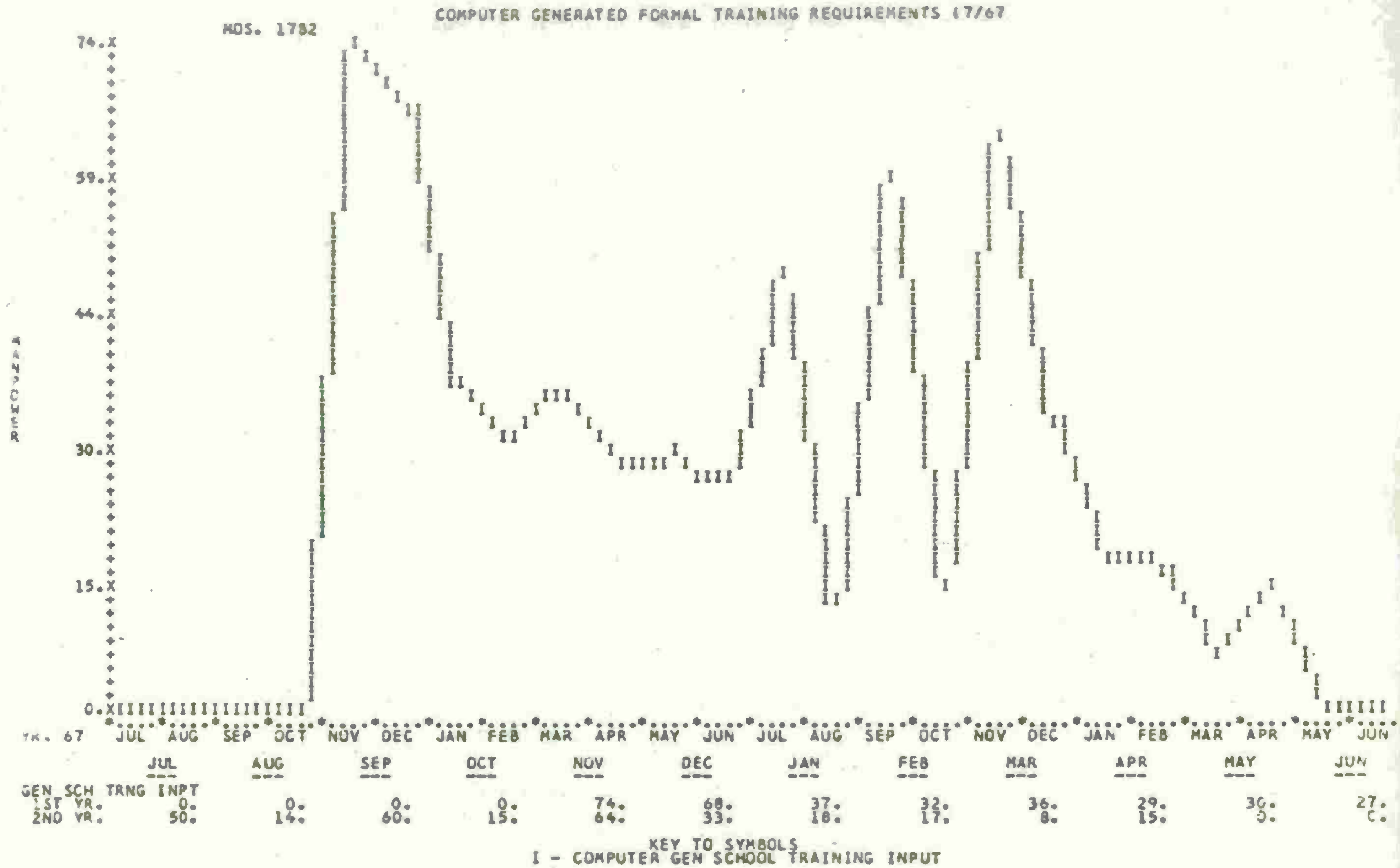


Fig 5—Computer-Generated Formal-Training Requirements for MOS 17B2

The Enlisted Distribution Report

As shown in Table 1, a computer printout from the Enlisted Distribution Report, projected assets are distributed to commands or segments of commands called command elements. Ordinarily, the data of an Enlisted Distribution Report are secret. In this case, fictitious authorization numbers are used. The MOS being distributed is 17B2. Across the top of the page 12 months, July through June are listed. Down the left-hand column are the names of command elements over which distribution occurs. There are six rows of data for each element, giving the authorized and allocated strength for the first and second years of the projection period. The system is capable of handling up to 100 command elements.

Command elements are categorized into three priority groups. For each group, totals and percent of fill (allocated strength divided by authorized strength) are displayed. The planner specifies the priority of each element and the desired rate of fill for each priority group. Note: rates of fill may be specified for a particular element that differs from the rate of the priority group to which the element belongs. Priority groups differ not only in rate of fill but in methods of allocation. Group I command elements that have the highest priority are allocated assets to the specified percent of authorization (called the desired rate of fill). If the inventory is too short to support even Group I to specified strength, then available assets, prorated by authorizations, are allocated to the elements.

Group II allocation varies by rate of availability (RV), a rate calculated by dividing the remaining inventory by the remaining authorized strength. The system user specifies desired rates of fill based on the rate of availability of the MOS. For instance, suppose that the following four RV ranges are specified:

Availability rate		Asset allocation
101 - 900	=	100
90 - 99	=	100
85 - 89	=	90
75 - 80	=	80

If the RV falls within any range on the left of the equal sign the assets allocated are the percent of authorized strength appearing on the right. If the RV does not fall within any RV range, the RV itself is used as the percent of authorized strength allocated.

In the above example the first range guarantees that the allocation will never exceed 100 percent. As many as ten such ranges may be specified. Group III elements are allocated assets based wholly on the RV up to 100 percent. If more assets are available they are allocated to a surplus category.

Table 1

Test Data: MOS Distribution by Command Element

ENLISTED MEN DISTRIBUTION
BY MOS FOR TWO YEARS BEGINNING JULY 1967
MOS - 1782

ELEMENT		JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MARCH	APRIL	MAY	JUNE
RVN	1ST YR AUTH	300	300	300	300	300	300	300	300	300	300	300	300
	M/L	300	300	300	300	300	300	300	300	300	300	300	300
	2ND YR AUTH	300	300	300	300	300	300	300	300	300	300	300	300
	M/L	300	300	300	300	300	300	300	300	300	300	300	300
SEA (LESS RVN)	1ST YR AUTH	100	100	100	100	100	100	100	100	100	100	100	100
	M/L	100	100	100	100	100	100	100	100	100	100	100	100
	2ND YR AUTH	100	100	100	100	100	100	100	100	100	100	100	100
	M/L	100	100	100	100	100	100	100	100	100	100	100	100
*** GROUP TOTAL	1ST YR AUTH	400	400	400	400	400	400	400	400	400	400	400	400
	M/L	400	400	400	400	400	400	400	400	400	400	400	400
(PERCENT OF FILL)		(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)
	2ND YR AUTH	400	400	400	400	400	400	400	400	400	400	400	400
	M/L	400	400	400	400	400	400	400	400	400	400	400	400
(PERCENT OF FILL)		(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)
EUROPE	1ST YR AUTH	100	100	100	100	100	100	100	100	100	100	100	100
	M/L	143	136	131	133	131	100	68	90	100	100	100	100
	2ND YR AUTH	100	100	100	100	100	100	100	100	100	100	100	100
	M/L	100	100	100	100	100	100	100	100	100	100	100	100
TRAINING BASE	1ST YR AUTH	50	50	50	50	50	50	50	50	50	50	50	50
	M/L	72	68	65	66	66	50	34	45	50	50	50	50
	2ND YR AUTH	50	50	50	50	50	50	50	50	50	50	50	50
	M/L	50	50	50	50	50	50	50	50	50	50	50	50
*** GROUP TOTAL	1ST YR AUTH	150	150	150	150	150	150	150	150	150	150	150	150
	M/L	215	204	196	199	197	150	102	135	150	150	150	150
(PERCENT OF FILL)		(143)	(136)	(130)	(132)	(131)	(100)	(68)	(90)	(100)	(100)	(100)	(100)
	2ND YR AUTH	150	150	150	150	150	150	150	150	150	150	150	150
	M/L	150	150	150	150	150	150	150	150	150	150	150	150
(PERCENT OF FILL)		(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)
STRAF I	1ST YR AUTH	50	50	50	50	50	50	50	50	50	50	50	50
	M/L	50	50	50	50	50	45	34	37	42	50	50	50
	2ND YR AUTH	50	50	50	50	50	50	50	50	50	50	50	50
	M/L	50	50	50	50	50	50	50	50	50	50	50	50
REM CONUS	1ST YR AUTH	8	8	9	9	9	69	146	148	148	148	150	150
	M/L	8	8	9	9	9	61	98	109	124	148	150	150
	2ND YR AUTH	150	150	150	150	160	160	160	160	160	160	160	160
	M/L	150	150	150	150	160	160	160	160	160	160	160	160
*** GROUP TOTAL	1ST YR AUTH	58	58	59	59	59	119	196	198	198	198	200	200
	M/L	58	58	59	59	59	106	132	146	166	198	200	200
(PERCENT OF FILL)		(100)	(100)	(100)	(100)	(100)	(89)	(67)	(73)	(84)	(100)	(100)	(100)
	2ND YR AUTH	200	200	200	200	210	210	210	210	210	210	210	210
	M/L	200	200	200	200	210	210	210	210	210	210	210	210
(PERCENT OF FILL)		(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)

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ELEMENT		JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MARCH	APRIL	MAY	JUNE
OTHER	1ST YR AUTH	0	0	0	0	0	0	0	0	0	0	0	0
	M/L	0	0	0	0	0	0	0	0	0	0	0	0
	2ND YR AUTH	0	0	0	0	0	0	0	0	0	0	0	0
	M/L	0	0	0	0	0	0	0	0	0	0	0	0
SURPLUS	1ST YR AUTH	0	0	0	0	0	0	0	0	0	0	0	0
	M/L	25	20	18	19	18	0	0	0	0	0	0	0
	2ND YR AUTH	0	0	0	0	0	0	0	0	0	0	0	0
	M/L	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL OF ALL COMMAND ELEMENTS	1ST YR AUTH	608	608	609	609	609	669	746	749	749	748	750	750
	M/L	698	682	673	677	674	656	634	681	716	748	750	750
	2ND YR AUTH	750	750	750	750	760	760	760	760	760	760	760	760
	M/L	750	750	750	750	760	760	760	760	760	760	760	760

Another feature of the model, called "forced assignment," is best explained with an example. For this purpose, Table 2 contains an extract of the report shown in Table 1.

As shown in Table 2 some of the command elements have been deleted as have all months except August 1967 and February 1968. Authorizations in the remaining CONUS (Continental Limits of the United States) increase from August to February. The projection report indicates an insufficient number of men available in February 1968. Group II elements receive 90 percent of the requirements whereas elements having a Group III priority rating receive only 73 percent. The user can specify that 17B2 is highly essential in the command element entitled "Remaining CONUS" in February 1968 and order that all 148 spaces be filled. In response the system will reallocate assets and change the result (arrows). Now remaining CONUS has 100 percent, bringing Group III to 93 percent of fill (other Group III elements are not shown) and cuts Group II down to 64 percent. This action demonstrates the result of moving personnel from Europe and other Group II command elements to CONUS. The shortage can be alleviated somewhat by the user specifying that only 130 spaces be filled in remaining CONUS instead of all 148.

This report is produced in two other formats, not shown here, with the information rearranged to emphasize different aspects of the data. The Enlisted Distribution Model is described in Appendix B.

The Officer Inventory Projection Report

Figure 6 is a sample of the Officer Inventory Projection Report in which the inventory is described by branch/grade, rather than MOS; however, the format is the same as that of the Enlisted Report. Figure 6 shows the projected assets and authorization for Colonels of the Infantry branch.

The officer projection works quite differently from that of the enlisted man. Several of 10 major attrition rules, depending on the characteristics of an officer, may apply. A MONTE CARLO procedure, using probabilities based on these characteristics, is applied to each officer whose record appears in active Army files. On the basis of this random procedure an officer's record either remains an asset for the year projected or is removed. The particular month of attrition is chosen in a random manner or is predetermined, depending on the type of attrition. The following attrition rules are considered:

(a) Mandatory, voluntary, and disability retirement
(b) Unqualified resignation
(c) Title 10 retirement
(d) Category declination
(e) Voluntary relief from active duty
(f) Temporary promotion passover separation
(g) Miscellaneous

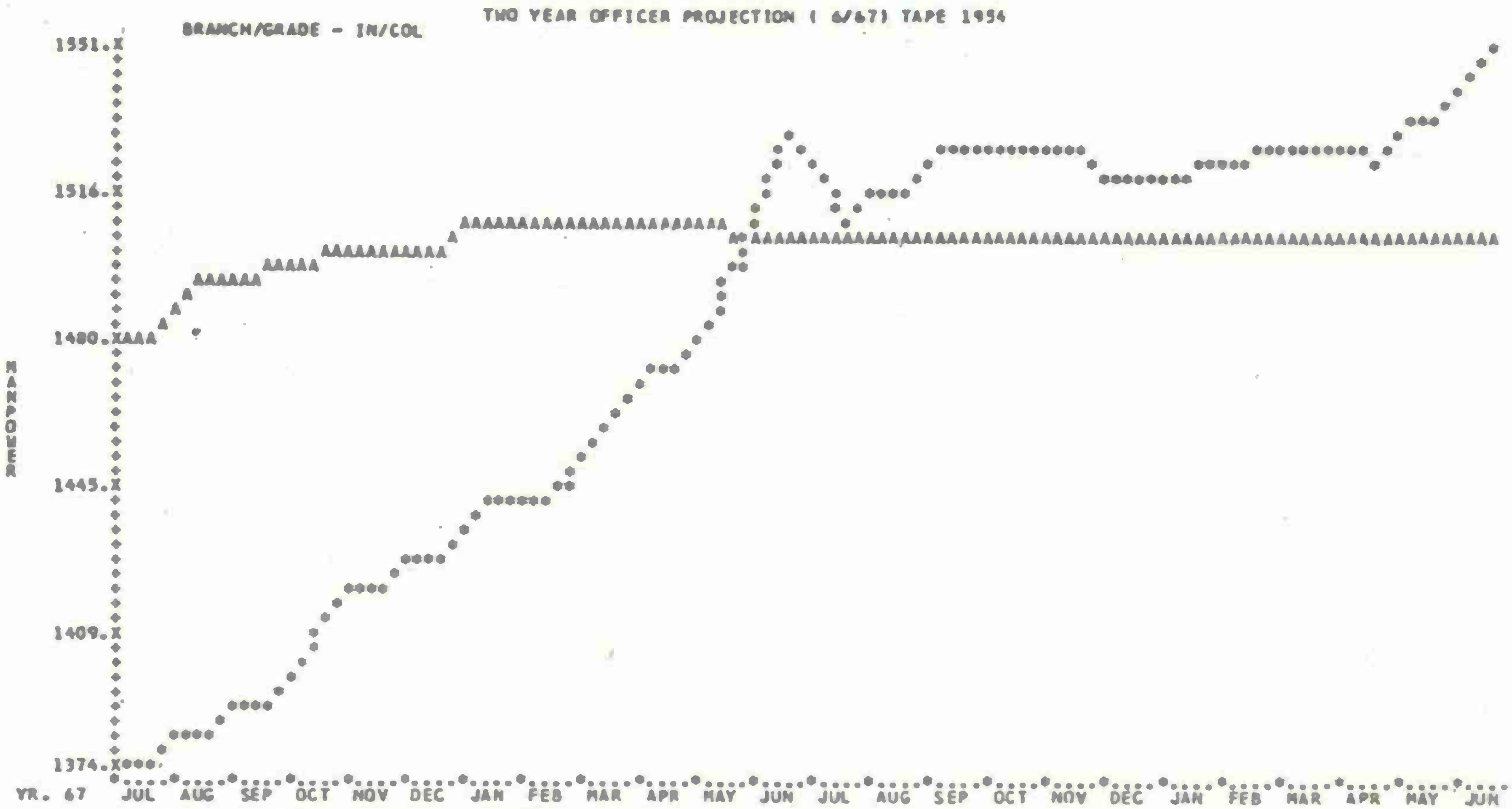
Table 2

ENLISTED MEN DISTRIBUTION

BY MOS FOR TWO YEARS BEGINNING JULY 1967

MOS – 17B

ELEMENT		AUG	FEB
RVN	1st Yr Auth	300	300
	M/L	300	300
	2nd Yr Auth	300	300
	M/L	300	300
*** Group Total			
(Percent of Fill)	1st Yr	(100)	(100)
(Percent of Fill)	2nd Yr	(100)	(100)
Europe	1st Yr Auth	100	100
	M/L	136	90 → 64
	2nd Yr Auth	100	100
	M/L	100	100
*** Group Total			
(Percent of Fill)	1st Yr	(136)	(90) → (64)
(Percent of Fill)	2nd Yr	(100)	(100)
REM CONUS	1st Yr Auth	8	148
	M/L	8	109 → 148 *
	2nd Yr Auth	150	160
	M/L	150	160
*** Group Total			
(Percent of Fill)	1st Yr	(100)	(73) → (93)
(Percent of Fill)	2nd Yr	(100)	(100)
Total of All Command Elements	1st Yr Auth	608	748
	M/L	682	681
	2nd Yr Auth	750	760
	M/L	750	760



	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
AUTHORIZATION												
1ST YR.	1481.	1495.	1498.	1504.	1504.	1504.	1511.	1511.	1511.	1511.	1507.	1507.
2ND YR.	1507.	1507.	1507.	1507.	1507.	1507.	1507.	1507.	1507.	1507.	1507.	1507.
INVENTORY												
1ST YR.	1374.	1386.	1394.	1413.	1423.	1430.	1442.	1448.	1466.	1476.	1501.	1530.
2ND YR.	1511.	1517.	1527.	1527.	1529.	1522.	1525.	1528.	1527.	1523.	1534.	1551.

KEY TO SYMBOLS
A - TOTAL PROJECTED INVENTORY
* - TOTAL PROJECTED AUTHORIZED STRENGTH

TOTALS	BEGINNING INVENTORY	GAINS PROMT	GAINS PROCU	GAINS TOTAL	LOSSES PROMT	LOSSES ATTRIT	LOSSES TOTAL	NET CHANGE	CLOSING INVENTORY
1ST YR	1402	294	0	294	11	155	166	128	1530
2ND YR	1530	210	0	210	12	177	189	21	1551

Fig 6—Officer Inventory Projection by Branch/Grade Infantry Branch, Colonel

The following characteristics of an officer are considered in calculating attrition:

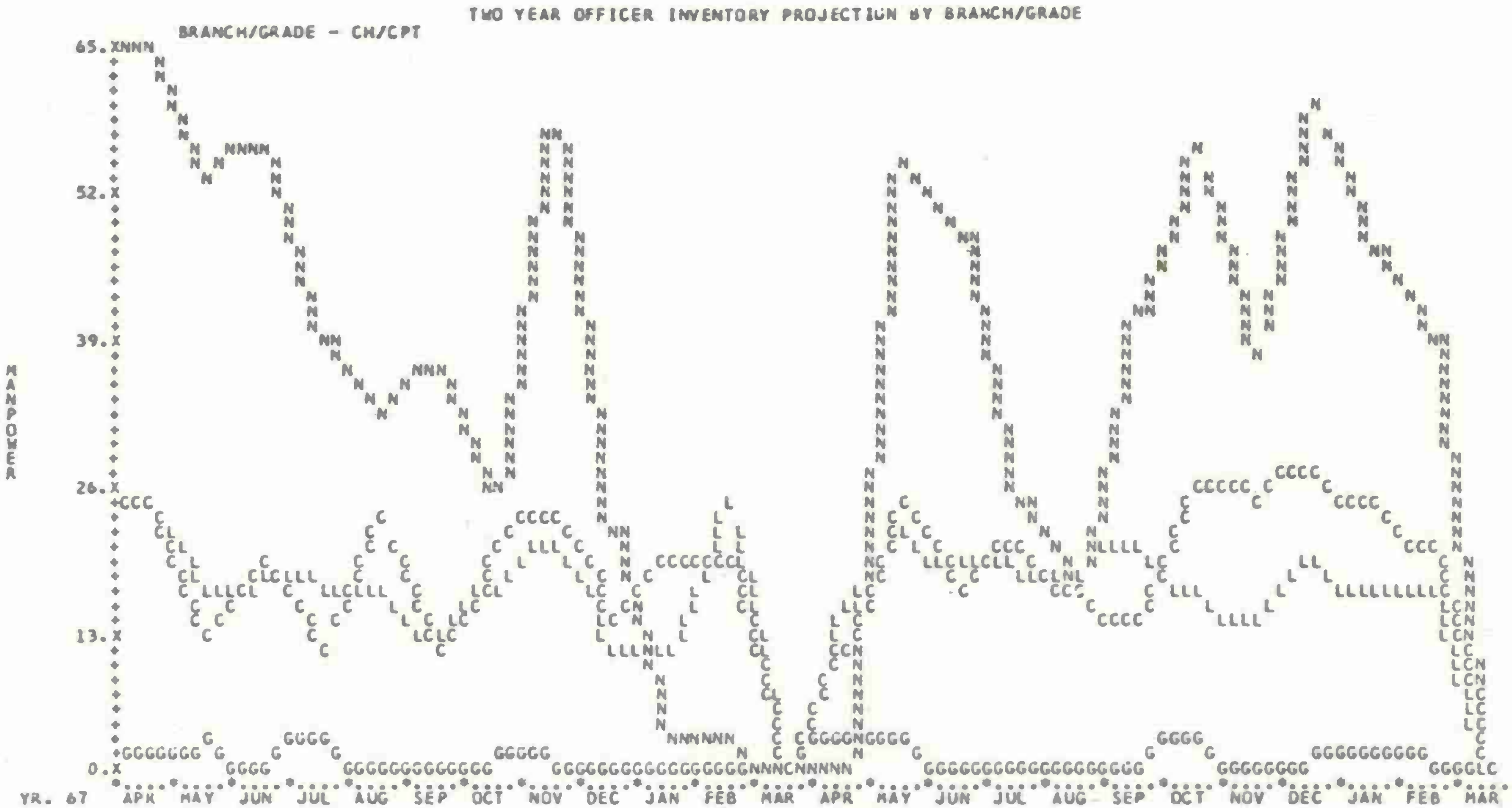
- Branch
- Component
- Temporary grade
- Permanent grade
- Temporary rank date
- Permanent rank date
- Procurement program number
- Age
- Category expiration date
- Service agreement
- Active Federal Commissioned Service (AFCS) date
- Active Federal Service (AFS) date
- Mandatory retirement date
- Regular Army (RA) appointment date
- Promotion status indicator
- Number of Army of the United States (AUS) passovers
- Last passover date

Projected officer attrition by cause is printed as a separate report as shown in the second page of the Officer Inventory Projection Report (Fig 7) all active Army losses are aggregated and called attrition losses. This example is for Chaplain Captains.

In the model officers are promoted by means of zone promotion and what is called "automatic" promotion. The number of promotions is controlled by the timing of attrition. When a space becomes empty, an officer is promoted into it. To a particular branch/grade, promotion is both a gain and a loss; hence, on this report promotion losses and promotion gains appear. In the example, promotion gains are very small because in the Chaplain branch procurement is primarily into the rank of Captain.

For grades being promoted by zone promotion, a zone of promotion eligibility based on months in grade is calculated by the model. Since only a percentage of officers eligible for promotion are actually promoted in real life, a MONTE CARLO procedure is applied to choose those promoted. Under "automatic" promotion, promotion takes place for a percent of all individuals reaching a number of months in grade as specified by the system user. Either type of promotion may be specified by the user for any grade.

Unlike the enlisted projection, the model is stochastic. A random procedure is used because promotions and procurement are tied to a yearly cycle, as are many of the attrition rules. The yearly cycle necessitates the recalculation of promotion zones and attrition factors for the second year with a beginning inventory containing individual records. Gains and loss rates cannot be applied, as they are for enlisted men, to category populations during the first year; it is necessary to apply rates to individuals and decide whether and in what form each will appear at the beginning of the second year. Hence, the necessity for randomness. Since



	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
PROMOTION GAINS												
1ST YR.	3.	5:	1:	5:	2:	1:	3:	0:	1:	2:	0:	0:
2ND YR.	4:	5:	2:	1:	2:	2:	5:	1:	3:	3:	2:	0:
PROMOTION LOSSES												
1ST YR.	26.	17.	19.	17.	18.	14.	18.	22.	12.	13.	26.	0.
2ND YR.	16.	23.	20.	19.	19.	22.	17.	15.	20.	17.	18.	0.
PROCUREMENT GAINS												
1ST YR.	65.	54:	56:	40:	33:	37:	27:	58:	23:	5:	5:	0:
2ND YR.	1.	55.	49.	25.	17.	42.	57.	39.	61.	48.	40.	0.
ATTRITION LOSSES												
1ST YR.	25.	14.	20.	13.	24.	13.	21.	24.	15.	20.	20.	0.
2ND YR.	13.	25.	18.	22.	17.	15.	27.	25.	28.	25.	21.	0.

KEY TO SYMBOLS
G - GAINS FROM LOWER RANK BY PROMOTION
L - LOSSES TO HIGHER RANK BY PROMOTION
N - GAINS FROM PROCUREMENT
C - LOSSES DUE TO ANY OF ATTRITION

Fig 7—Officer Inventory Projection, Gains and Losses Chaplain Branch, Captain

the second year of the projection is simply a repetition of the first-year algorithm applied to the year-end inventory, the model can be repeated for any number of inventories.

The Officer Distribution Report

Table 3 shows a page of the Officer Distribution Report. (Again the numbers are fictitious.) The model has all the features of the Enlisted Distribution Model plus the ability to do limited grade-substitution. If a command element belonging to priority Group I or II has a shortage of commissioned officers when aggregated across all grades of one branch, the distribution model will attempt to alleviate the shortage by filling spaces with personnel of a lower grade. As shown in Table 3, the Group I commands received only 94 percent of the requirement for Artillery Captains and the two Group II commands did not recieve Artillery Captains. The situation is rectified by over-allocating Lieutenants, to rates of fill of 104 percent and 162 percent. Thus, the commands are brought to an overall rate of fill of 100 percent and 86 percent, respectively, (the desired priority group rates of fill specified for the run).

The shortage is rectified for a Group II element only if the rate of availability of the lowest grade in the branch doesn't fall below a specified minimum. In the above example, if the rate of availability of Lieutenants had fallen below the Group III minimum (here specified at 50 percent) only Lieutenants in excess of this rate would have been assigned to Group II, thereby alleviating but not eliminating the shortage.

If a Group II command element is allocated a level of fill well over the desired rate, the allocations are drawn down for those grades contributing most to the overage. This routine is followed until the overall allocation to the element is equal to the specified rate of fill. This does not mean that instances may occur where the resulting rate-of-fill in Group II is lower than that for Group III elements. The specified rate of fill is modified when and if the rate of availability is greater. For instance, assume the overall rate of fill specified for Group II is 85 percent and the rate of availability across all grades is 95 percent. Under this condition if Group II were cut back to 85 percent in allocation, Group III would receive over 95 percent of its requirements. In this instance the model will consider 95 percent as the desired rate of fill for Group II elements.

Appendix D contains a further description of this model.

CAPABILITY ANALYSIS AND ALTERNATIVE PLAN DEVELOPMENT

The second successive step in the P.I.A. System, although not fully complete, now permits limited performance of capability analysis. Work is continuing at RAC on this aspect of the study. Study on the third step, alternative plan development and analysis also is being conducted at RAC.

Table 3

Test Data: Officer Distribution by Command Element

(August 1967; Branch, Artillery)

Element	Colonel		Lieutenant Colonel		Major		Captain		Lieutenant		Total		Percent
	Auth-orized	Manning level	Auth-orized	Manning level	Auth-orized	Manning level	Auth-orized	Manning level	Auth-orized	Manning level	Auth-orized	Manning level	Percent
Republic of Vietnam	300	300	700	700	1000	1000	1700	1594	3000	3106	6700	6700	100
Southeast Asia less RVN	300	300	600	600	800	800	1500	1406	2000	2094	5200	5200	100
Group total	600	600	1300	1300	1800	1800	3200	3000	5000	5200	11900	11900	
Percent fill	(100)		(100)		(100)		(94)		(104)		(100)		
Europe	100	129	400	400	500	400	1200	0	1500	2236	3700	3165	86
Training base	100	129	400	400	500	400	1200	0	1000	1808	3200	2737	86
Group total	200	258	800	800	1000	800	2400	-0	2500	4044	6900	5902	
Percent fill	(129)		(100)		(80)		(0)		(162)		(86)		
Strategic Army Forces 1	100	100	250	200	500	333	600	0	1200	1200	2650	1833	69
Remaining CONUS	50	50	250	200	400	267	300	0	1200	1200	2200	1717	78
Group total	150	150	500	400	900	600	900	-0	2400	2400	4850	3550	
Percent fill	(100)		(80)		(67)		(0)		(100)		(73)		
Other	0	0	0	0	0	0	0	0	0	0	0	0	0
Surplus	0	42	0	0	0	0	0	0	0	556	0	598	0
All elements (total)	950	1050	2600	2500	3700	3200	6500	3000	9900	12200	23650	21950	

The capability analysis report consists of two parts. The first identifies problem areas such as quantitative or qualitative shortages, and ranks these problem areas in order of criticality. The second part presents a diagnosis of the problem with possible problem causes. Part one, a "flagging and ranking" procedure, is operational. The validity and effectiveness of the procedure are now undergoing "dry run" exercises. Part two is in an early design stage. The Alternative Plan Development phase also is in the early stages of design.

When complete the Capability Analysis and Alternative Plan Development phases will address the task of reviewing a spectrum of problems (and would-be problems) and assist in defining, and reducing them to a manageable few. The System will offer great assistance in finding the appropriate answer(s) to the problem(s) that have been established.

Appendix A

ENLISTED INVENTORY PROJECTION MODEL

INTRODUCTION

In this appendix and those which follow, the major models appearing in this paper are presented in mathematical notation. For ease of presentation, each model has been subdivided into logical submodels. Each submodel is represented by one or more formulas followed by an explanation of symbols. Multiplication is always represented by a dot • while the absence of an operator between a symbol and another symbol in parentheses denotes a function (i.e., PR(m) expresses "projected retainables" as a function of the month, m). A symbol may consist of more than one alphabetic character. In that case the symbol is an acronym of the defining phrase such as SG denoting scheduled gains.

Projected Retainables for a Four Position MOS

$$PR(m) = \left[x - \left(\frac{PR(m-1) + x}{2} \cdot NA \right) \right] \cdot \left[1 - TPS(m) \right]$$

where $x = [PR(m-1) + SG(m) - PL(m)] \cdot (1+Sp)$

when m=1,	PR(m-1)	=	Beginning inventory
	m	=	Month of projection ($1 \le m \le 24$)
	PR	=	Projected retainables
	SG	=	Scheduled gains
	PL	=	Projected losses
	Sp	=	Seepage factor for MOS ($-1 < Sp < 1$)
	NA	=	Normal attrition factor for MOS. ($0 \le NA < 1$) (If not available for MOS, NA = 0.005)
	TPS	=	Transient, patient, student rate for MOS and month

$$\text{TPS rate} = \text{Seasonal weighting factor} \cdot \frac{\text{TPS inventory on EMTR for MOS}}{\text{Inventory of MOS on EMTR}} \quad (0 \le TPS(m) < 1)$$

Scheduled Gains for an MOS

$$SG(m) = STO(m) + CA(m)$$

where $STO(m) = \sum_{i=1}^{n} SI_n(D+L) \cdot (1-SA)$

and $D+L = m$

m = Month of projection
SG = Scheduled gains
STO = Scheduled training output
SI = Scheduled class input
N = Number of class beginning month m for this MOS
D = Reporting date of class
L = Length of course
SA = School attrition factor for this MOS
CA = Direct civilian accession to MOS

Projected Losses for an MOS

$$PL(m) = ET(m) + SFL(m) + CL(m) + RT(m) + OC(m)$$

where $$ET(m) = \sum_{i=1}^{3} (Pr_E(MOS,C) \cdot PR(m-1,C))$$

$$RT(m) = \sum_{y=19}^{31+} (Pr_R(MOS,y) \cdot PR(m-1,y))$$

$$SFL(m) = \sum_{i=0}^{n} STO_i(m,MOSF)$$ where n = number MOSs fed by this MOS.

CL(m) = Loss Factor (MOS) • Projected Total Army Losses for month m.

where $$\text{Loss Factor (MOS)} = \frac{\text{Historical Losses for MOS}}{\text{Total Historical Losses}}$$

m = Month of projection
PL = Projected losses
ET = Projected ETS loss
SFL = Scheduled training feeder loss
CL = Projected casualty loss
RT = Projected retirement loss
OC = Projected loss to MOS for Officer Candidate School
Pr_E = Probability of separation due to ETS, by MOS and component
C = Component; AUS, RA first term, RA career
PR = Projected retainables by month and component or years of service
Pr_R = Probability of retirement by MOS and years of service or total Army and years of service
y = Years of service
STO = Scheduled training output by month and MOS
MOSF = An MOS fed by the MOS under consideration.

Projected Inventory for an MOS

$$I(m) = PR(m) + PT(m) - PFL(m)$$

$$PT(m) = [AT(m) \cdot (1+TPS(m)) \cdot RF - PR(m) \cdot (1 + TPS(m)) + PFL(m)]$$

$PFL(m) = \sum_{i=1}^{n} PT(m)$ The training output requirements for n MOSs drawing assets from the MOS under consideration.

If n = 0, then PFL(m) = 0.

$$PT(m) \leq CS(MOS) < AV(m)$$

$$AV(m) = \begin{cases} AT(m) \cdot RF - [PR(m) + PT(m)] & (1) \\ \left[AT(m) \cdot \frac{I(m-1)}{AT(m-1)}\right] - \left[PR(m) + PT(m)\right] & (2) \end{cases}$$

AV(m) = (2) only if RF is not specified for the MOS under consideration and (2) > (1).

If the feeding MOS feeds more than one MOS, the available assets are distributed prorated according to requirements of the receiving MOS.

For entry level MOSs only (fed by 09B0) the availability formula (AV_E) becomes:

$$AV_E(m) = AV(m) \cdot \text{Trainee factor}$$

where $0 \leq$ Trainee factor ≤ 1 and is calculated based on the availability of trainees and the priority of the MOS under consideration.

m	=	Month of the projection
I	=	Projected inventory
PR	=	Projected retainables
PT	=	Projected training output requirements
PFL	=	Projected feeder loss due to projected output requirements
CS	=	Maximum monthly class size for MOS if school trained
AV	=	Number of men available for retraining in feeding MOS. All terms in the formula for AV refer to the feeding MOS.
AT	=	Authorized strength for MOS
RF	=	Rate of fill for MOS specified by user.

Appendix B

ENLISTED DISTRIBUTION MODEL

This model distributes projected assets to authorized strength at a level called command element (CE). A CE is normally defined by command area and assignment codes. Up to one hundred CEs can be handled by the model. The distribution method categorizes CEs into three priority groups. Following are distribution methods of each group. (See Introduction of App A.)

By MOS and Month

Group I

$$\delta_1(CE) = AT(CE) \cdot RF(CE) \cdot \alpha$$

where $$\alpha = \begin{cases} RV \text{ if } RV < 1 \\ 1 \text{ if } RV \geq 1 \end{cases}$$

$$RV = INV(MOS) \Big/ \sum_{i=1}^{N} AT(CE_i) \cdot RF(CE)$$

Group II

$$\delta_2(CE) = AT(CE) \cdot \beta$$

where $$\beta = \begin{cases} X, \text{ if } x \leq RV \leq y = X;\ x,\ y,\ X \text{ specified by user} \\ RV \end{cases}$$

and $$RV = \frac{INV(MOS) - \sum_{i=1}^{N_1} \delta_1(CE_i)}{\sum_{i=1}^{N} AT(CE_i) - \sum_{i=1}^{N_1} AT(CE_i)}$$

Group III

$$\delta_3(CE) = AT(CE) \cdot RV$$

where $$RV = \frac{INV(MOS) - \left[\sum_{i=1}^{N_1} \sum_{j=1}^{N_2} (\delta_1(CE_i) + \delta_2(CE_j))\right]}{\sum_{i=1}^{N_3} AT(CE_i)}$$

$$\text{Surplus} = INV(MOS) - \sum_{j=1}^{3} \sum_{i=1}^{N_j} AT_j(CE_i)\ RF(CE_i)$$

if and only if >0.

Forced assignment prior to all groups:

δ_F = Specified or forced assignment

Inventory and authorizations are decremented accordingly

δ_i = Assets allocated to command element CE which belongs to group i (i=1,2,3)

AT = Authorized strength for CE

RF = Desired rate of fill for CE

α = Group I availability factor

RV = Rate of availability

INV = Projected inventory for month for MOS

β = Group II availability factor

N_i = Number of command elements in group i (i=1,2,3)

N = Total number of CEs

CE = Command element

Appendix D

OFFICER DISTRIBUTION MODEL

The distribution of projected manpower inventory to command elements (see Appendix B) is calculated for each branch/grade individually. The distribution algorithm to branch/grade is the same as that applied to MOS in the enlisted distribution model. However, this model differs in that it considers the distribution to a CE for a branch aggregated across all grades. If the total branch distribution for a group I or II command element is below the specified rate of fill, limited substitution takes place. If a group II element branch distribution is over the recommended rate of fill selected, grade distributions are decreased.

Following is a description of the model in mathematical terminology, each priority group described individually.

For an explanation of "forced assignment" which is an option in this model, see Appendix B.

The distribution depicted is for one branch, b.

<u>Group I</u>

$$\delta_1(CE,g) = AT(CE,g) \cdot RF_1(CE) \cdot \alpha$$

$$\text{where } \alpha = \begin{cases} RV_1 \text{ if } RV_1 < 1 \\ 1 \text{ if } RV_1 \geq 1 \end{cases}$$

$$RV_1 = \frac{INV(b,g)}{\sum_{i=1}^{N} AT(CE_i,b,g) \cdot RF_1(CE)}$$

Note: See Introduction of Appendix A.

$$\text{If} \sum_{i=1}^{5} \delta_1(CE,g_i) - \sum_{i=1}^{5} AT(CE,g_i) \cdot RF_1(CE) = K < 0$$

$$\text{then} \quad \delta_1(CE,LT) = \delta_1(CE,LT) + |K|$$

Group II

$$\delta_2(CE,g) = AT(CE,g) \cdot \beta$$

$$\text{where} \quad \beta = \begin{cases} X \text{ if } x \le RV_2 \le y = X & \text{where } x, y, X \text{ are specified by user} \\ RV_2 \end{cases}$$

$$RV_2 = \frac{INV(b,g) - \sum_{i=1}^{N_1} \delta_1(CE_i,g)}{\sum_{i=1}^{N} AT(CE_i,g) - \sum_{i=1}^{N_1} AT(CE_i,g)}$$

$$\text{If} \sum_{i=1}^{5} \delta_2(CE,g_i) - \sum_{i=1}^{5} AT(CE,g_i) \cdot \rho = K < 0$$

$$\text{where} \quad \rho = \begin{cases} RF_2(CE) \text{ if } RF_2(CE) \ge RV \\ RV_2 \text{ if } RF_2(CE) < RV \end{cases}$$

$$\text{then} \quad \delta_2(CE,LT) = \delta_2(CE,LT) + |K|$$

$$\text{only if } RV_3(LT) - |K| = \frac{INV(b,g) - \left(\sum_{j=1}^{N_1} \delta_1(CE_j,LT) + \sum_{j=1}^{N_2} \delta_2(CE,LT) \right) - |K|}{\sum_{i=1}^{N_3} AT(CE,LT)} \ge RF_3$$

However, if

$$RV_3(LT) - |K| < RF_3$$

but $RV_3(LT) > RF_3$

then $\delta_2(CE,LT) = \delta_2(CE,LT) + \left[\sum_{i=1}^{N_3} AT(CE_i,LT) \cdot (RV_3(LT) - RF_3)\right]$

If $K > 0$

then beginning at the lowest grade where

$\delta_2(CE,g) > 0$, δ_2 is reduced such that $\delta_2 \geq AT \cdot \rho$ until $K = 0$.

<u>Group III</u>

$$\delta_3(CE,g) = AT(CE,g) \cdot RV_3$$

$$\text{where } RV_3(CE,g) = \frac{INV(b,g) - \left[\sum_{i=1}^{N_1} \delta_1(CE_i,g) + \sum_{i=1}^{N_2} \delta_2(CE_i,g)\right]}{\sum_{i=1}^{N_3} AT(CE_i,g)}$$

$$\text{Let } \Theta(CE,g) = \begin{cases} INV(b,g) - \sum_{i=1}^{n} AT(CE_i,g) \cdot RF(CE_i) \text{ if } > 0 \\ 0 \text{ if } \leq 0 \end{cases}$$

$$\text{Surplus } (CE,g) = \sum_{i=1}^{N_3} \Theta(CE_i,g)$$

CE = Command element

b = Branch

g = Grade

δ_i = Distribution to CE in group i (i = 1,2,3)

AT = Authorized strength for branch b

RV_i = Rate of availability for group i.and branch b

INV = Inventory of branch grade

RF_i = Desired rate of fill for group i.and branch b

LT = Grade of lieutenant

α = Group I availability factor

β = Group II availability factor

θ = Surplus of a branch grade in group III, over 100%

K = Constant

The definition of the function ρ prevents group II rate of fill from ever being lower than that of group III.

MINIMIZATION OF TRAINING COST AND QUANTITY OF MULTI-SKILLED PERSONNEL UNDER CONTINGENCY SKILL REQUIREMENT CONDITIONS

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I. INTRODUCTION

A. Problem Situation

In the aviator system, training decisions are made daily. One question which arises often is "Should an experienced aviator who is presently qualified in aircraft A and B be transition trained in aircraft C against an aviator requirement for aircraft C or should he fill requisitions only for aircraft A and B while a 'new' aviator is trained in aircraft C?" Before this day-to-day decision can be made in an optimum manner, a more fundamental question must be raised. What should the overall training goal be for Army aviators from a cost-benefit viewpoint? In other words, is there an optimum mix of aviators who can fly only one aircraft and aviators who can fly two aircraft or three aircraft? An example of aviator policy regarding training goals follows.

That all aviators should be dually qualified (qualified in both rotary and fixed wing aircraft) is a generally accepted aviator goal. Sound reasons exist for this. First, some high-level aviator positions require detailed knowledge of both rotary and fixed wing aircraft. Secondly, manpower distribution or rotation problems are considerably lessened if an aviator can serve in either a fixed or rotary wing position. Other reasons may include morale, etc.

Unquestionably, the reasons are sound. However, perhaps this goal should be examined on a cost basis. Questions which immediately arise are

1. How many requirements actually exist for dual-qualified aviators?
2. Are the additional retraining costs actually worthwhile? In other words, what is the increment in morale and rotation maneuverability for each increment in training costs?
3. Is the optimum goal less than 100% dual qualification?

Ramifications of these questions are immense and progress will be slow in finding complete answers.

This paper presents an algorithm for determining a goal for the quantity of single and multi-skilled aviators needed to meet aviator requirements for a number of contingent conflicts. (Skills refer to aircraft qualifications in this model of aviators.)

Let us define total requirements as the sum of the requirements necessary to meet current requirements and contingency force requirements. The contingency force is a reserve force who are immediately

available for flying duty in the event of a sudden breakout of hostilities over and above the current aviator requirements. The algorithm calculates contingency force requirements and assigns the aviators to an aircraft under each contingency.

The key to the optimum mix of single and multiple-skilled aviators is the alternative aviator requirements which are planned under various contingencies. For example, the ratio of fixed to rotary wing aircraft in Vietnam is certainly different from the same ratio in a potential European conflict. This occurs because of the differences in terrain. It follows that the bulk of Vietnam requirements are for aviators who can fly various rotary wing aircraft while the opposite would be true in a European conflict.

At any given time OSD and the Army have plans for a number of contingencies. Presumably, each of these may be met with a different mix of aircraft qualification requirements for aviators. Each requirement would be appropriate for the location and other parameters of the conflict. The problem is to calculate the optimum mix of single and multiple aircraft-qualified aviators needed that can meet any of the alternate contingencies 100% and do this with minimum cost and manpower. This is the mix of aviators which the training base should be striving to maintain.

The solution found by the algorithm is a goal for the training policies. It does not solve the more difficult problem of how to make the daily decisions so that the goal can be maintained or swiftly attained if the training mix is presently not optimum.

B. General Approach

The algorithm can calculate a minimum cost and manpower solution under the conditions where requirements are for single skills (i.e., A or B or C and not both A and B).

The following additional assumptions are also made in the present algorithm:

1. Requirements must be met 100% no matter which of the contingent hostilities occur.
2. All combinations of aircraft qualifications can be accommodated by the training base. In other words, there is no restriction on the combination of aircraft qualifications that a single aviator can have.[1]

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[1]Actually the algorithm could be easily modified to restrict the acceptable combinations of qualifications.

5. Requirements, which are input to the algorithm, are optimally derived after consideration of the implications of morale, rotation, maneuverability, etc., discussed previously.

It should be noted that the relative or actual costs of each type of qualification (skill) is not necessary for solution of the problem as it is defined.

Minimum cost and manpower of the contingency force is achieved when the following conditions are met:

1. The total aviator requirements equal the maximum total requirements under any contingency. If total requirements were less than this, total requirements could not be met if that contingency which requires a maximum number of men occurred.
2. The number of aviators who can fly each aircraft should equal the maximum requirement for that aircraft among all contingencies. Again, it is obvious that training requirements can be no less than the maximum needed if requirements must always be met 100%.

If both of these conditions are met simultaneously, both manpower and costs are minimized. This is the "optimum" solution sought by the algorithm and referred to in the model.

Particular sets of requirements exist which do not have an optimum solution and the algorithm will come to this conclusion. At the point when it concludes that only a nonoptimum solution is possible, it will have chosen a large majority of personnel in an optimum manner. Thus, a solution can still be achieved which is much better than methods other than the algorithm would have provided. In fact, solutions can still be found which minimize either manpower or training costs. These "nonoptimal" solutions will be discussed in a subsequent paper.

In general, the algorithm trains personnel in a single skill if there is a requirement in that skill for them to fill under <u>every</u> contingency. It trains multi-skilled aviators when it locates a set of aircraft which have maximum requirements remaining under <u>different</u> contingencies and, therefore, an aviator fills different aircraft requirements under different contingencies.

The steps making up the algorithm enable groups of personnel to be selected at a time. Personnel comprising a group are trained in the same skill(s) and assigned to a requirement under each contingency. After a group has been selected and assigned, requirements are correspondingly reduced and the algorithm reiterates its search for another group of personnel. It continues its search and selection of personnel until requirements have been reduced to zero or it determines that they cannot be reduced to zero under optimum conditions.

II. DESCRIPTION OF THE ALGORITHM

The complete mathematical formulation of the algorithm may be found in the appendix. A summary of the steps of the algorithm and an example of its application will be presented in this section.

A. Algorithm Steps

1. Form the requirements matrix with skills as columns and contingencies as rows.
2. Subtract column minimums from each requirement and, for each column, select a number of men equal to the column minimum and train them in the column skill only.
3. If any row has no requirements remaining, delete the row from the matrix and go back to 2.
4. If all column maximums are in the same row, an optimum solution is achieved by selecting, for each column, a number of men equal to the column maximum and training them only in the column skill. If column maximums are not all in the same row, continue with 5.
5. Conduct an orderly search among all pairs[1] of columns for a pair that does not have column maximums in the same row and every row has a nonzero row sum over the pair of columns. If no set of columns is found, go to 9.
6. Calculate

   [(minimum row sum) + (maximum row sum) - (sum of column maximum values)]

   for the selected set of columns. If the result is positive, select

   [(sum of column maximums) - (maximum row sum)] personnel to be

   trained in all of the selected column skills and fill requirements in that set of columns. If the result is negative or zero, select (minimum row sum) personnel.
7. Reduce each row sum by the number of personnel selected above. To determine which column's requirements to reduce and by how much, (i.e., assign selected personnel to a skill), follow these rules:

   a. Always reduce column maximums by the entire number of selected personnel.
   b. Do not reduce a requirement below zero.
   c. No requirement remaining after reduction shall exceed (old column maximum - number of selected personnel).
   d. If more than one reduction combination satisfies b. and c., select the combination which minimizes the different requirement values remaining and gives best fit with other column maximums for future searches under 5.

8. If all requirements equal zero, the optimum solution has been

[1] If a pair is not found, next search column triplets, etc, until a set of columns satisfies the specifications.

found. If at least one requirement does not equal zero, continue the algorithm beginning at 3.

9. Determine the rows which do not have any column maximums. If none, go to 10. If there are such rows, determine for each column the maximum of the requirements for the selected rows. Select for each column a number of men equal to the maximum determined above and train them only in that column skill. Subtract the maximums determined above from each requirement in its column. Continue the algorithm at 3.
10. If more than one reduction combination did satisfy 7 b and 7 c during one selection of men, disregard all selections of men after that selection and continue the algorithm from that point using a different reduction combination. If all possible reduction combinations have been attempted and none have led to an optimal solution, no optimum solution is attainable.

B. Example of the Algorithm

Figure 1 presents a hypothetical problem with five contingency plans that have varying requirements in each of five skills. Numerical values are not related to any real values and are used for illustration only.

Figure 1

Aircraft

		A	B	C	D	E	Total Requirements
Contingency Plans	1	13	12	6	8	7	46
	2	4	12	22	5	3	46
	3	4	16	14	5	7	46
	4	13	1	8	12	12	46
	5	2	1	5	4	8	20
		13	16	22	12	12	

The "skills" in this example are the training courses which qualify pilots to fly different aircraft. The five aircraft are designated A, B, C, D, and E.

The five "contingency plans" are designated 1, 2, 3, 4, and 5, and each row shows the aviator requirements if that contingency occurs. For example, if contingency 2 occurs, 4 aviators who are qualified to fly aircraft A are required, 12 aviators for aircraft B, 22 aviators to fly aircraft C, 5 aviators for aircraft D, and 3 aviators to fly aircraft E.

The column maximums are shown at the bottom of each column. The right-most column shows the total requirements for each contingency plan. Four of the five plans have the same totals because it seems reasonable

that this represents the manpower ceiling currently imposed on aviators. This means that the same total number of aviators are available to meet various contingencies.

If individuals were never qualified in more than one aircraft, the manpower requirement would be 75, the sum of the column maximums. This would be a minimum training cost solution but the requirement for 75 men greatly exceeds the maximum total requirement for any contingency which is 46.

Criteria for minimization of both cost and manpower requirements have been discussed in Section I B. Their application to this problem shows that a solution is desired that requires 46 men who are trained so that exactly 13 men are qualified in aircraft A, 16 in aircraft B, 11 in aircraft C, 12 in aircraft D, and 12 in aircraft E. In addition, the training mix of the aviators will enable all requirements to be met 100% for any of the contingencies.

The original requirements are shown in simplified form as matrix (1) on Figure 2. Each numbered section following explains the algorithmic movement from the corresponding matrix on Figure 2 to the next matrix.

(1) There is a minimum number of aviators needed in each skill no matter which contingency occurs. Therefore, it is least costly to qualify that number of aviators in only that skill.

The number of aviators to be qualified in each aircraft and the requirement they are filling under each contingency is shown under columns labeled Matrix Number "1" on Figure 3. For example, 5 aviators will be trained only in aircraft C and will fill a requirement for C under each contingency.

Subtracting these from the requirements in matrix (1), we have matrix (2).

(2) This selection step will be explained in more detail than the following steps for two reasons: 1) It demonstrates the more difficult aspects of the algorithm and 2) It is the first selection of aviators who must be qualified in more than one aircraft. No contingencies have zero requirements remaining. Thus we continue by circling all column maximums. Systematically checking all pairs of qualifications, B and E are the first pair which do not have maximum requirements in the same row and have nonzero requirements for either B or E for every contingency. The minimum sum of requirements for B and E among all contingencies is 5 for 5 contingencies. The maximum is 19 for contingency 3. The circled maximum for each qualification are 15 and 9 for B and E, respectively.

According to the algorithm, find the result of (max row sum + min row sum - sum of column maximums). This gives 5 + 19 - (15+9) = 0.

Therefore, the number of aviators to be selected from matrix (2) is the minimum sum of requirements, 5. If the result had been positive, the number of persons to be selected is calculated by subtracting the maximum sum of B and E requirements in any row from the sum of the circled maximums for B and E.

For these five aviators who have been selected to be trained to fly aircraft B and E, the problem arises as to how to optimally assign these aviators under each of the contingencies. Should they fill B or E requirements under each contingency? It is obvious that under contingency 5 they will fill E requirements as it is under contingency 2, for which only B requirements need to be filled.

The algorithm requires that selected aviators always fill requirements that are column maximums. Therefore, under contingency 3 the aviators will fill B requirements and under contingency 4, they will fill E requirements.

However, for contingency 1, any of the following combinations will satisfy the conditions in Step 7 of Section II A.

$(B, E)^1 = (1,4)^2$
or (2,3)
or (3,2)
or (4,1)
or (5,0)

Combination (5,0) was chosen for contingency 1 because it minimized the number of <u>different</u> requirement values remaining in B and E. In addition, it seems to provide the basis for a C and E selection group in the future because of the row locations of the new column maximums for C and E skills. (See matrix (3) on Figure 2.) To summarize, 5 aviators qualified in B and E will be assigned to the different contingencies in the following manner.

Assignment	Contingency
B ⟶	1
B ⟶	2
B ⟶	3
E ⟶	4
E ⟶	5

[1] (0,5) is not acceptable because the remaining requirement for E is only 4.

[2] (1,4) means fill 1 B requirement and 4 E requirements.

Subtracting 5 aviators from requirements indicated above leaves requirements as shown in matrix (3).

(3) The fifth contingency has no remaining requirements so that it can be removed from the matrix. It is now optimum to qualify a number of aviators in a single aircraft equal to the minimum value in each matrix column (excluding contingency 5) as was done with matrix (1) at the beginning of the algorithm. The number selected are shown in Figure 3 under matrix number 3. The result of subtracting these minimums from the requirements for each contingency is now matrix (4).

(4) No contingencies have zero requirements remaining. Continuing, A and B satisfy requirements of Step 5 of the algorithm.

Minimum row sum = 6
Maximum row sum = 15
Column maximum for A = 9
Column maximum for B = 10

$6 + 15 - 9 - 10 = 2$

Because the result is positive, the number of aviators selected for both A and B qualification is equal to the sum of the column maximums minus maximum row sum or,

$9 + 10 - 15 = 4$

By following the rules of Step 7, the assignment of these 4 aviators is shown on Figure 3.

(5) - (9) In each of these matrices the same pattern is followed as has been explained for the previous matrices.

(10) No pair of columns satisifies the condition that every row has a nonzero row sum. However, the set of columns B, C, and D satisfy the search conditions.

∴ min row sum = 2
max row sum = 2
B column maximum = 2
C column maximum = 2
D column maximum = 2

and $2 + 2 - (2 + 2 + 2) = -2$

Therefore, 2 persons are selected and must be qualified in aircraft B, C, and D. Looking at matrix (10), it is obvious that the 2 persons trained in aircraft B, C, and D will be assigned in this manner.

B ———————— 1

C ———————— 2

B ———————— 3

D ———————— 4

The number of personnel selected and their assignment is recorded under matrix number 10 on Figure 3.

Because all remaining requirements now equal zero, an optimum solution has been found.

The totals shown in Figure 3 verify that the optimality criteria have been satisfied. A total of 46 aviators are required for the total contingency force which equals the maximum required under any contingency. Of the 46 aviators

13 are qualified in aircraft A
16 are qualified in aircraft B
22 are qualified in aircraft C
12 are qualified in aircraft D
12 are qualified in aircraft E.

These figures equal but do not exceed the maximum requirements for each skill under any contingency.

The aircraft assignments of the aviators under each contingency are also summed by aircraft. These totals agree with the requirements in the original matrix. Minimum training cost and manpower have been attained by the algorithm.

Figure 2

Matrices Showing Progression of the Algorithm

(1)

	A	B	C	D	E
1	13	12	6	8	7
2	4	12	22	5	{3}
3	4	16	14	5	7
4	13	{1}	8	12	12
5	{2}[1]	{1}	{5}	{4}	8

(2)

	A	B*[3]	C	D	E*
1	11[2]	11	1	4	4
2	2	11	17	1	0
3	2	15	9	1	4
4	11	0	3	8	9
5	0	0	0	0	5

(3)

	A	B	C	D	E
1	11	6	{1}	4	4
2	{2}	6	17	{1}	{0}
3	{2}	10	9	{1}	4
4	11	{0}	3	8	4
5	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~

(4)

	A*	B*	C	D	E
1	9	6	0	3	4
2	0	6	16	0	0
3	0	10	8	0	4
4	9	0	2	7	4

(5)

	A*	B	C*	D	E
1	5	6	0	3	4
2	0	2	16	0	0
3	0	6	8	0	4
4	5	0	2	7	4

(6)

	A	B*	C*	D	E
1	0	6	0	3	4
2	0	2	11	0	0
3	0	6	3	0	4
4	0	0	2	7	4

(7)

	A	B*	C	D*	E
1	0	4	0	3	4
2	0	2	9	0	0
3	0	4	3	0	4
4	0	0	0	7	4

(8)

	A	B	C*	D*	E
1	0	2	0	3	4
2	0	0	9	0	0
3	0	2	3	0	4
4	0	0	0	5	4

(9)

	A	B	C*	D	E*
1	0	2	0	0	4
2	0	0	6	0	0
3	0	2	0	0	4
4	0	0	0	2	4

(10)

	A	B*	C*	D*	E
1	0	2	0	0	0
2	0	0	2	0	0
3	0	2	0	0	0
4	0	0	0	2	0

(11)

	A	B	C	D	E
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0

[1] { } means the value is a column minimum.

[2] ○ means the value is a column maximum.

[3] * means that these columns satisfied conditions in Step 5 (II A).

Figure 3

Selection and Contingency Assignment of Aviators

Matrix Number		1	1	1	1	1	2	3	3	3	4	5	6	7	8	9	10	TOTALS				
Number Selected		2	1	5	4	3	5	2	1	1	4	5	2	2	3	4	2	46				
Training Required		A	B	C	D	E	B E	A	C	D	A B	A C	B C	B D	C D	C E	B C D	A	B	C	D	E
																		13	16	22	12	12
Aircraft Assignment Under Each Contingency	1	A	B	C	D	E	B	A	C	D	A	A	B	B	D	E	B	13	12	6	8	7
	2	A	B	C	D	E	B	A	C	D	B	C	C	B	C	C	C	4	12	22	5	3
	3	A	B	C	D	E	B	A	C	D	B	C	B	B	C	E	B	4	16	14	5	7
	4	A	B	C	D	E	E	A	C	D	A	A	C	D	D	E	D	13	1	8	12	12
	5	A	B	C	D	E	E	-[1]	-	-	-	-	-	-	-	-	-	2	1	5	4	8

[1]A dash means that the personnel selected in this column do not fill any requirements under contingency 5.

III. SUMMARY AND FUTURE PLANS

A. Summary and Discussion

A model of the aviator contingency force assumes that future requirements of aviators to fly specific aircraft are uncertain and depend partially on the location of potential hostilities as well as other parameters.

It is given that m sets of requirements exist for m different contingencies and that each contingency has a requirement for each of n aircraft qualifications.

The algorithm provides the quantity of personnel who should be qualified in each possible combination of aircraft and their aircraft assignment under each contingency. It minimizes overall costs by limiting total aviator manpower to the maximum required under any contingency and limiting the number of men qualified in each aircraft to the maximum required under any contingency. The algorithm also assures that all requirements will be met 100% no matter which contingency occurs.

Experience with the algorithm has shown that more than one "optimum" solution may exist for particular sets of requirements. Other sets have no "optimum" solution. It is believed that the algorithm is applicable to requirement matrices of any size although computational experience is limited as yet.

If situations exist where it is not possible for personnel to have certain combinations of skills, the algorithm can be easily modified to accept this restriction. To do this, the search for sets of skills (II A 5) will not be made for the illegal combinations of skills.

B. Further Research

The primary limitation of the algorithm is that requirements must be described in terms of single skills. If the requirements are thought of as jobs or positions, they are best described as combinations of skills in many cases. For example, high level aviator command requirements may specify that the person be dually qualified.

In other words, the requirements matrix should allow requirements to be specified by combinations of aircraft qualifications which are found in actual aviator jobs as well as single aircraft qualifications.

There are other points in which the assumptions of the present model do not completely satisfy the "real-life" aviator system. However, now that a solution algorithm exists for the less restrictive assumptions, it is hoped that a modified version of this algorithm will be applicable in more complex environments.

Acknowledgment

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APPENDIX

Mathematical Model

A. Definitions

X = Total number of personnel required

C = Total cost (training + induction costs)

X_j = Total number of personnel who will be trained in skill j, where $j = 1, 2, \ldots, n$

${}_p r_{ij}$ = Requirement under the i-th contingency plan for the j-th skill after the p-th group of personnel have been selected and assigned, where $i = 1, 2, \ldots, m$; $j = 1, 2, \ldots, n$; $p = 0, 1, \ldots, q$; ${}_p r_{ij} \geq 0$ and integral

${}_p x(k_1\ k_2 \ldots k_m)$ = Number of persons to be trained in a particular combination of of skills and their skill assignment under each of the m contingencies,

where x = number of persons,

k_i = skill to which these persons will be assigned under contingency i.

These persons will be trained only in the skills represented among the m values of k and not trained in other skills. e.g., ${}_2 8(343-)$ means that the second selected group of 8 persons should be trained in skills 3 and 4. They will perform skill 3 under contingencies 1 and 3, skill 4 under contingency 2, and will not be needed under contingency 4.

$c(k_1\ k_2 \ldots k_m)$ = Cost of inducting and training one person in the combination of skills represented among the m values of k.

$_p r_{ij} = \max \left\{ {}_p r_{1j}, {}_p r_{2j}, \ldots, {}_p r_{mj} \right\}$, where $j = 1, 2, \ldots, n$

$_p r'_j = \min \left\{ {}_p r_{1j}, {}_p r_{2j}, \ldots, {}_p r_{mj} \right\}$, where $j = 1, 2, \ldots, n$

R_i = Sum of requirements under the i-th contingency plan

$$= \sum_{j=1}^{n} {}_o r_{ij}$$

$\underline{R} = \max \left\{ R_1, R_2, \ldots, R_m \right\}$

x_p = p-th group of x persons to be trained where $x_p = x$ in $_p x(k_1 \ldots k_m)$

B. Criteria for Optimality

a. $X = \min \left[\sum_p {}_p x(k_1\ k_2 \ldots k_m) \right]$

b. $C = \min \left[\sum_p c(k_1\ k_2 \ldots k_m)\ {}_p x(k_1\ k_2 \ldots k_m) \right]$

To satisfy these objectives, it is clear that the solution algorithm will satisfy both of the following criteria if it is to minimize both manpower and costs simultaneously.

c. $X_j = {}_o r_{ij}$ for $j = 1, 2, \ldots, n$

d. $X = \underline{R}$

The objective of the algorithm is to find values of $_p x(k_1\ k_2 \ldots k_m)$ which will satisfy c and d and all requirements under each contingency.

C Algorithm Steps

Step 1: Form an m x n matrix containing all $_o r_{ij}$ with the i-th contingency plan occupying the i-th row and the j-th skill occupying the j-th column.

Step 2: Determine $_p r'_j$ for each $j = 1, 2, \ldots, n$.

Step 3: If $_p r'_j \neq 0$, set $_p x(k_1 \ldots k_n) = {}_p r'_j(\ j\ j \ldots j)$ for each j.

Step 4: $_{p+1} r_{ij} = {}_p r_{ij} - {}_p r'_j$ for all i, j.

Step 5: If ${}_p r_{i1} = {}_p r_{i2} = \dots = {}_p r_{in} = 0$ for any value of i, delete row i from the matrix and return to Step 2.

Step 6: Determine ${}_{p-1} r_{ij}$ for all j. If $i = i'$ for every $j = 1, 2, \dots, n$, then set ${}_p x(k_1\ k_2 \dots k_n) = {}_{p-1} r_{ij}(\ j\ j \dots j)$ for each j. The optimal solution is achieved. If $i \neq i'$ for every j, continue the algorithm.

Step 7: An orderly and exhaustive search must not be initiated to locate a pair of columns which satisfy conditions 7a and 7b. Let j' and j" be the columns under inspection.

7a) $i_o \neq i_1$ for all pairs $({}_{p-1} r_{i_o j'}, {}_{p-1} r_{i_1 j''})$,

where i_o takes on all values of i for which ${}_p r_{ij'} = {}_{p-1} r_{ij'}$, and i_1 takes on all values of i for which ${}_p r_{ij''} = {}_{p-1} r_{ij''}$.

This condition states that maximums in j' and j" columns may not occur in the same row.

7b) For no value of i does ${}_p r_{ij'} = {}_p r_{ij''} = 0$. This condition says that for the skills under consideration, j' and j", every contingency must have a nonzero requirement in either j' or j".

If none of the ${}_2C_n$ pairs of columns satisfy 7a and 7b, search all of the ${}_3C_n$ triplets, then the ${}_4C_n$ groupings, etc., until all of the $2^n - 1$ combinations of skills have been inspected. (Steps 7-11, although stated in terms of a pair of skills under inspection, can be easily generalized to any number of skills.) If none of the $2^n - 1$ combinations of skills satisfy 7a and 7b, go to step 13. However, if columns j' and j" do satisfy 7a and 7b, continue with Step 8.

Step 8: Determine $\min_i ({}_p r_{ij'} + {}_p r_{ij''})$ and $\max_i ({}_p r_{ij'} + {}_p r_{ij''})$.

Step 9: If $\left[\min_i ({}_p r_{ij'} + {}_p r_{ij''}) + \max_i ({}_p r_{ij'} + {}_p r_{ij''}) - ({}_p \underline{r}_{ij'} + {}_p \underline{r}_{ij''})\right] > 0$, set $x_{p+1} = {}_p \underline{r}_{ij'} + {}_p \underline{r}_{ij''} - \max_i ({}_p r_{ij'} + {}_p r_{ij''})$; otherwise, set $x_{p+1} = \min_i ({}_p r_{ij'} + {}_p r_{ij''})$.

Step 10: It will be optimum to select x_{p+1} persons to be trained in skills j' and j". By definition,

$$x_{p+1} = {}_p r_{ij'} + {}_p r_{ij''} - ({}_{p+1} r_{ij'} + {}_{p+1} r_{ij''}), \text{ for every } i$$
$$= ({}_p r_{ij'} - {}_{p+1} r_{ij'}) + ({}_p r_{ij''} - {}_{p+1} r_{ij''}).$$

Determine ${}_{p+1} r_{ij'}$ and ${}_{p+1} r_{ij''}$ for all i according to these rules.

10a) Subtract x_{p+1} wholly from all column maximums $({}_p \underline{r}_{ij})$, i.e., ${}_{p+1} \underline{r}_{ij} = {}_p \underline{r}_{ij} - x_{p+1}$.

10b) In rows which do not contain column maximums, satisfy both of these conditions:

-- The remainder in either column does not exceed the new column maximums $({}_{p+1} \underline{r}_{ij})$ as calculated under a, i.e., ${}_{p+1} r_{ij} \leq {}_{p+1} \underline{r}_{ij}$ for all i and j = j', j".

-- ${}_{p+1} r_{ij} \geq 0$ for all i and j = j',j"

If these conditions can be satisfied by more than one combination of $({}_{p+1} r_{ij'}, {}_{p+1} r_{ij''})$, select the combination which minimizes the number of different values of ${}_{p+1} r_{ij'}$ and ${}_{p+1} r_{ij''}$ and appears to give the best fit with other column maximums for future selections.

Step 11: This step assigns the x_p personnel to either skill j' or j" for each of the m contingencies. However, if either ${}_p r_{ij'}$ or ${}_p r_{ij''} = 0$ for all rows not having a column maximum $({}_{p}\underline{r}_{ij})$, assignments are obvious and this step can be skipped.

Let ${}_{p+1}x_{ij} = {}_p r_{ij} - {}_{p+1}r_{ij}$. Form the m x 2 matrix $({}_{p+1}x_{ij})$, $i = 1, 2, \ldots, m$, $j = j', j''$.

11a) Find $\min_i({}_{p+1}x_{ij'}) > 0$. Then $\min_i({}_{p+1}x_{ij'}) = x$ in ${}_{p+1}x(k_1\ k_2\ \ldots\ k_m)$.

11b) If ${}_{p+1}x_{ij'} \geq \min_i({}_{p+1}x_{ij'})$ for any i, then $k_i = j'$ in ${}_{p+1}x(k_1\ k_2\ \ldots\ k_m)$. If ${}_{p+1}x_{ij'} = 0$ for any i, then $k_i = j''$ in ${}_p x(k_1\ k_2\ \ldots\ k_m)$.

11c) Subtract $\min_i({}_p x_{ij'})$ from all ${}_p x_{ij}$ where assigned in the $({}_p x_{ij})$ matrix and repeat 11a-11c, if necessary, until all elements are zero.

Each iteration of 11a-11c produces a group of personnel with unique assignments for a different portion of the x_p individuals who are trained in j' and j".

Step 12: Determine if every element of $({}_{p+1}r_{ij}) = 0$. If so, the optimum solution has been achieved. If one element, ${}_{p+1}r_{ij'} \neq 0$, continue the algorithm at Step 5.

Step 13: Determine the rows in $({}_p r_{ij})$ for which ${}_p r_{ij} \neq {}_{p}\underline{r}_{ij}$ for every j. If there are rows satisfying this condition, let them be i*. If no rows satisfy this condition, go directly to Step 16.

Step 14: Determine $\max({}_p r_{i*j})$ for each $j = 1, 2, \ldots, n$ where $i*$ takes on all values of i determined in Step 13.

Step 15: Return to Step 3 and continue, substituting $\max({}_p r_{i*j})$ for each reference to ${}_p r'_j$.

Step 16: The algorithm cannot lead to an optimum solution as it has been implemented to this point.

It must be reapplied beginning with the first selection of persons in which more than one combination of $({}_p r_{ij'}, {}_p r_{ij''})$ would satisfy the conditions in Step 10b. Disregard all selections of men after that point in the algorithm and return to Step 10 using a different combination of $({}_p r_{ij'}, {}_p r_{ij''})$.

If Step 16 is again entered during the algorithm, continue to satisfy 10b with different combinations of $({}_p r_{ij'}, {}_p r_{ij''})$. If all combinations have been attempted and none have led to an optimum solution, an optimum solution is not possible.

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A TIME DEPENDENT ARTILLERY EVALUATION MODEL

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Before describing the time dependent artillery evaluation model, I would like to describe the problem we are attempting to solve and some of the weak points of previous models that led to the development of an evaluation model that considers time dependency of events.

The basic problem we are attempting to solve is to choose among many candidate artillery systems those which either add to existing capabilities or those which can significantly reduce the cost of maintaining a given level of effectiveness.

The basic approach that had been used to attack this problem is shown in Figure 1. The left branch reflects the firepower requirements imposed on the artillery resources of the right branch. To generate the data describing the requirements for the artillery to meet, a war game is played wherein both friendly and enemy units encounter each other in a land engagement. The battle is frozen at interesting points and the positions of enemy units are plotted on maps. The totality of these enemy positions constitute the threat.

At this point, the activation of a family of sensors is simulated. Analysis of the sensor data yields a list of acquired targets. The pertinent features of these acquired targets are:

- Size
- Posture - Standing, prone, or dug in personnel, tanks, armored personnel carriers, SAM sites, etc.
- Location error
- Casualty or vehicle damage requirement
- Location
- Environment - Town, woods, grassland, or open terrain.

The portions of the acquired targets that would be attacked by non-artillery systems are removed from the list. The remaining targets in the list represent the firepower requirements to be met by the artillery.

The artillery resources are represented by a mix or family of weapons selected from existing weapons and one or more candidate systems. The pertinent features of these artillery weapons are:

- Lethality of their munitions
- Accuracy
- Minimum and maximum range
- Rate of fire
- Munition reliability
- Crated weight per round
- Total cost per round.

The requirements and resources are combined in the effectiveness computation. Number of rounds and associated ammunition weight and cost are determined for each of the weapons in the trial mix to attack each of the targets in the threat.

Each target is then allocated to the weapon in the trial mix which can attack it with minimum ammunition weight or cost, whichever criteria is chosen. For each weapon, a summary is given of weight and cost of ammunition expended and the number of targets allocated to it.

The analysis of results consists in comparing ammunition weight and cost for different trial mixes to attack the targets in the threat. Care must be taken that all mixes being compared are capable of attacking the same set of targets else both cost and effectiveness vary simultaneously and the results thus become indeterminate.

Many variations can be played on the basic theme. Dynamic programming can be employed to find compromise allocations that are not quite minimum weight but significantly reduce cost compared to the true minimum weight allocation. Fixed costs can be considered by computing total cost for trial mixes to defeat a predetermined number of threats using the equation:

$$\text{Total Cost} = \text{Fixed Cost} + \text{Ammunition Cost per Threat} \times \text{Number of Threats}$$

Much usage has been made of this model and many good decisions have been made based on its results. Experience with this model led to increased appreciation of its weaknesses and qualifications included in studies using this model highlighted a few problem areas.

A weapon designed to attack specific target types is given an inherent advantage in the model when compared to weapons that do a fair job on a wide variety of targets. The balance between specialization and generalization of weapons in the artillery arsenal must therefore be made somewhat subjectively.

The model is inherently limited to making relative comparisons. What is needed can be measured but not how much. Merely deploying weapons systems in numbers proportional to the portion of the threat they attack is not an exact technique because in some cases, the number deployed depends upon expenditure requirements rather than on targets attacked.

Comparing costs for equal effectiveness is difficult because often unit costs depend upon the quantity purchased. As a temporary expedient, quantities were parameterized, but more precise measurement of quantities were being demanded so that costs could be compared more reliably.

Since analysis of the results of the model depends upon comparing costs for equal effectiveness, it is difficult to measure the impact of adding weapons with increased capabilities. If there are sets of targets which no weapon except the candidate system can attack, how can cost and return due to this increased capability be measured?

The greatest problem area associated with the model is suboptimization. In real combat situations, many demands are placed on artillery systems in short periods of time. The best weapon to do specific jobs may simply not be available in sufficient quantities at the right time and place. The job must be done by suboptimal weapons if at all. An accumulation of these uneconomical weapon-target assignments may make predicted cost savings false.

This last phenomenon was labeled "Surge" by the Department of Defense. Surge was a new concpet to us and required the formulation of a workable definition before we could extend our model to evaluate it in all its ramifications. The definition adopted for this term which permitted quantitative treatment is:

> "An artillery force is in a surge situation when the total number of fire missions presented to the force over a period of time exceeds the number of fire missions the force can perform."

With this definition to work from, an extension of the model to include the dimension of time was undertaken. The resultant model is shown in its entirety in Figure 2. Rather than attempt a detailed explanation of the entire chart, I will try to isolate the basic components, explain pertinent details, and relate the effect of time and how it is considered.

Figure 3 shows the way firepower requirements are assessed in the model. The crosshatched portions of the schematic show the parameters that were considered in the older model. The dashed boxes show relationships of various firepower requirement aspects to other portions of the model.

As before, a threat is generated by the play of a war game. Deployments of enemy units are given as a function of time. The missions to be performed by the artillery are separated into two categories: acquired targets and other artillery missions. Figure 4 shows the types of missions included in each of the categories.

Occurrences of other missions are computed from frequency considerations and prorated to time and place rather than played directly in the game.

Sensor activation is simulated and analysis made of the sensings to generate a list of acquired targets. Target characteristics are recorded as before, but some additional information is required. The time of acquisition of each target, its estimated departure time, the Fire Direction Center (FDC) to which the sensor reports, and the total casualty and vehicle damage inflicted by all systems so far are recorded. The need for acquisition and departure time will become obvious as we get deeper into the model. The FDC to which the sensor reports affects the choice of available fire units to undertake the mission and will be explained in more detail later. Since many of the enemy units will be acquired and fired upon several times throughout a combat day, some provision must be made to assess damage done prior to the current acquisition and to eliminate units from further consideration when sufficient damage has been done to render them ineffective.

From the two sets of artillery missions - targets and other missions - are selected those that occur at a specific time. At the beginning of the simulation, the clock is initiated and increased incrementally when all missions occurring at its current setting have been processed.

The missions occurring at a particular time are sorted according to the priority with which they would be considered by artillery commanders. The higher priority missions are processed first so that their demands on artillery resources can be met before those of lower priority missions.

The resultant current mission list constitutes the total firepower demands that are placed on the artillery at that time. Figure 5 shows a schematic of the artillery resources available at that time to fulfill these requirements. The dashed boxes and shaded boxes have the same connotations as before.

In addition to the characteristics of the weapons constituting a trial mix, the organization for combat of the weapons in the mix must be considered.

For each weapon in the trial mix, the number of fire units composed of that weapon is given. Each fire unit is assigned to an appropriate FDC. In the evaluation model presently being used, five FDC's are considered. An FDC is employed for each of three brigades of a division, a division artillery FDC, and an FDC controlling corps artillery units operating in the division sector. Each artillery unit in the trial mix is assigned to one of these FDC's.

Geographic deployment of artillery units together with a schedule for movement of each unit as the threat requires is also considered.

To process a mission from the current mission list an assessment is made of weapon availability for each fire unit of the trial mix that is assigned to the FDC to which the sensor acquiring the mission reports. For each of these fire units, assessment is made as to how many rounds the fire unit can expend on this mission. This information is obtained from knowledge of the current ammunition inventory status, fire unit to mission range, whether the unit is busy performing another mission, and whether it is currently redeploying. The ammunition inventory available to a unit consists of its basic load plus the ammunition supplied less the ammunition expended by the unit.

Expenditures are computed for single fire units or combinations of fire units to obtain required casualties or damage on the estimated target. Number of casualties and vehicles damaged are determined on the target elements actually at the site fired upon for each combination of attacking weapons.

The next step in the simulation model is the allocation of missions to fire units. If the mission can be performed by one or more units under control of the appropriate FDC, determination is made according to a predetermined criterion of which combination of units is to be employed. Some of the criteria that have been considered are least ammunition weight, least ammunition cost, least ratio of rounds expended to rounds available and least range. The mission is performed. Ammunition inventory and firing time of the engaging units are adjusted, and these units are keyed

to be busy for other missions occurring in the same time period. Assessment is made of the casualties or vehicle damage inflicted by the selected fire units. The casualties and vehicles damaged are accumulated for subsequent acquisitions of the enemy unit represented by the mission. If the damage is great enough, subsequent acquisitions are eliminated from the list of acquired targets.

If the mission cannot be performed by any combination of weapons available to the FDC under consideration, the mission is passed on to the next higher echelon for further consideration if the expected duration time allows this to be done. If the mission is already at the highest echelon (corps), it is deferred until the next time increment. If it will have departed by the next time period, the mission is recorded as permanently lost. As will be shown, the total number of such missions lost by a mix in a day of combat is a significant measure of the mix's performance.

This completes the description of the simulation model. In evaluation of artillery the next factors to consider are the measures to be used to compare mixes. The measures initially considered were categorized into measures of effort and measures of effectiveness. The measures of effort considered were:

- Fixed cost of mix
- Ammunition crated weight
- Ammunition dollar cost
- Number of artillery personnel required
- Total elapsed firing time.

The measures of effectiveness considered were:

- Missions completed
- Enemy units rendered ineffective
- Missions not accomplished
- Casualties inflicted
- Vehicles damaged.

Of these measures some were eliminated either because they could be better analyzed outside the context of the simulation or because they duplicated other more general measures. In the former category are fixed cost of mix and number of personnel required; the latter category includes total elapsed fire time, missions completed, and enemy units rendered ineffective. The significant measures selected are thus reduced to five:

- Dollar cost of expended ammunition
- Crated weight of expended ammunition
- Casualties inflicted
- Armored vehicles damaged
- Missions permanently lost.

To compare effectiveness returns for several mixes given a budgeted amount of money, the above measures can be plotted as a cumulative function of time measured in days of combat. To the ammunition cost is added the fixed cost associated with the fire units in the trial mixes. For an interesting level of total cost, mixes can be compared based on the total weight of ammunition expended, total casualties and vehicle damage inflicted, and days of combat elapsed. Other analyses involving constant weight, casualties, vehicles or combat days can be performed.

Most of the objections to the old model have been thus overcome. Specialized weapons can be added as long as their return justifies their cost. Force levels can be determined if the amount budgeted to artillery is known. Equal effectiveness as well as equal cost comparisons among alternatives can be made. Suboptimization due to surge is simulated directly. By varying assumed tactics, rules of thumb can be developed for the commander to get the most effectiveness from his artillery based on knowledge available to him at the time he must make decisions.

It is a symptom of progress, I guess, that now that these problems have been addressed, we are faced with a new set. Some of these can be attacked by refining the present model. Some can be approached by extending the present model into a two-sided simulation of artillery performance. The remaining problems will require a further extension to a combined arms two-sided war game. The insight into weapon performance and tactical usage gained in the process of developing this model assures that the extension will be carried out if for no other reason than the innate curiosity of good scientists. Advances in

computer technology will ease the process. Ultimately the decision maker will demand and be provided quantitative data as to weapon performance versus weapon cost in absolute terms. The American people will then know that the systems they are buying will yield the results expected.

Figure 1. Previous Evaluation Model

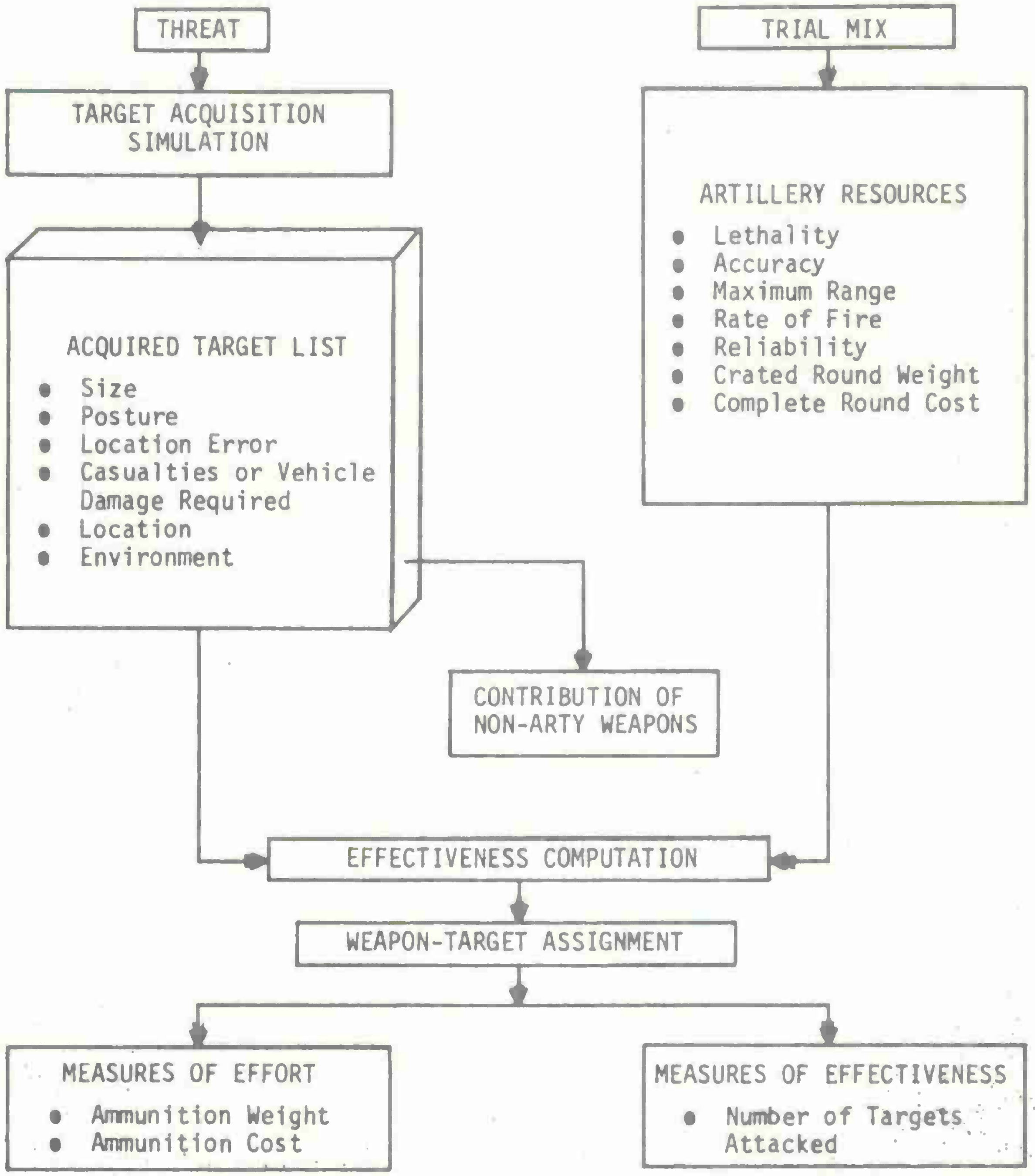


Figure 2. Time Dependent Evaluation Model

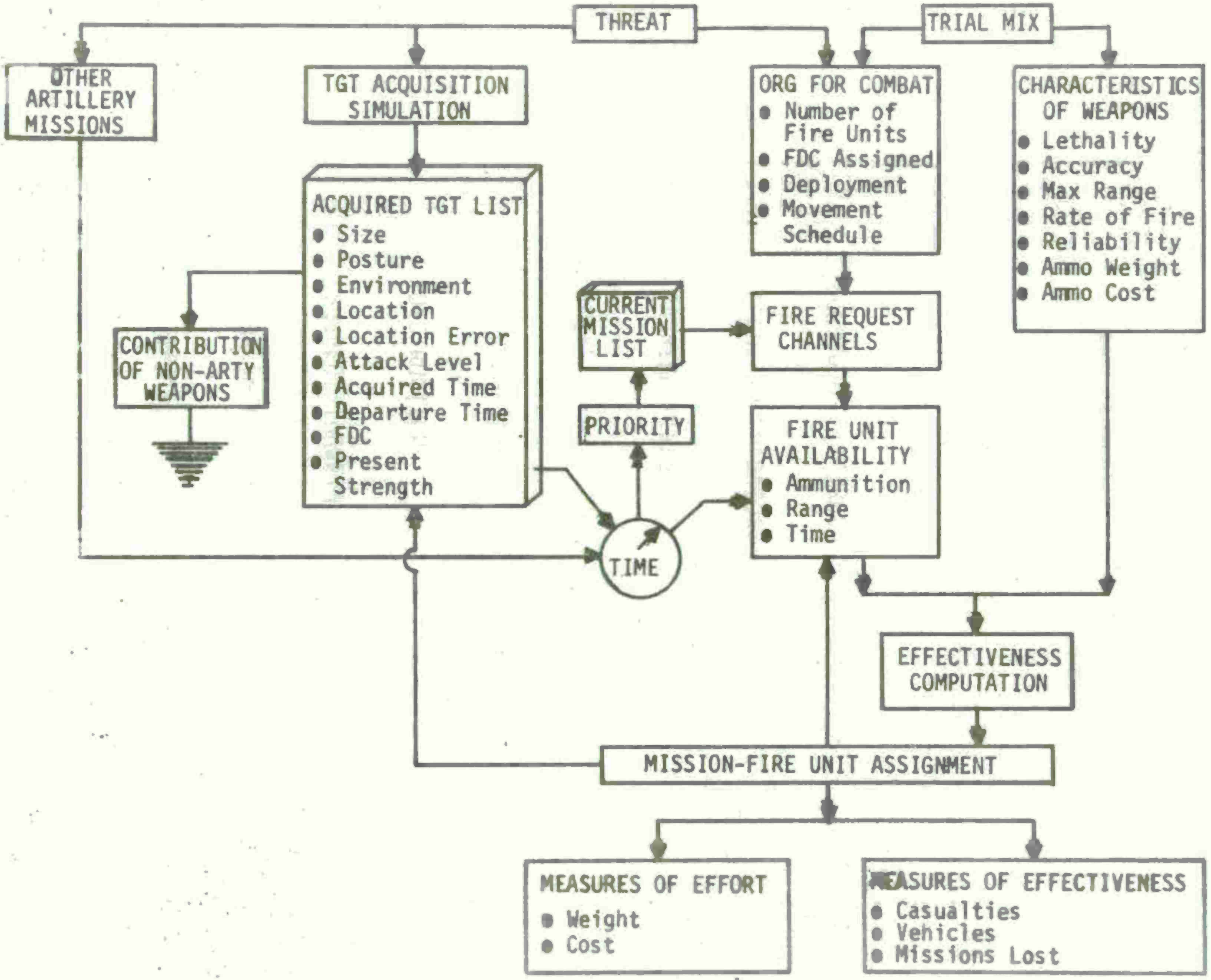


Figure 3. Firepower Requirements

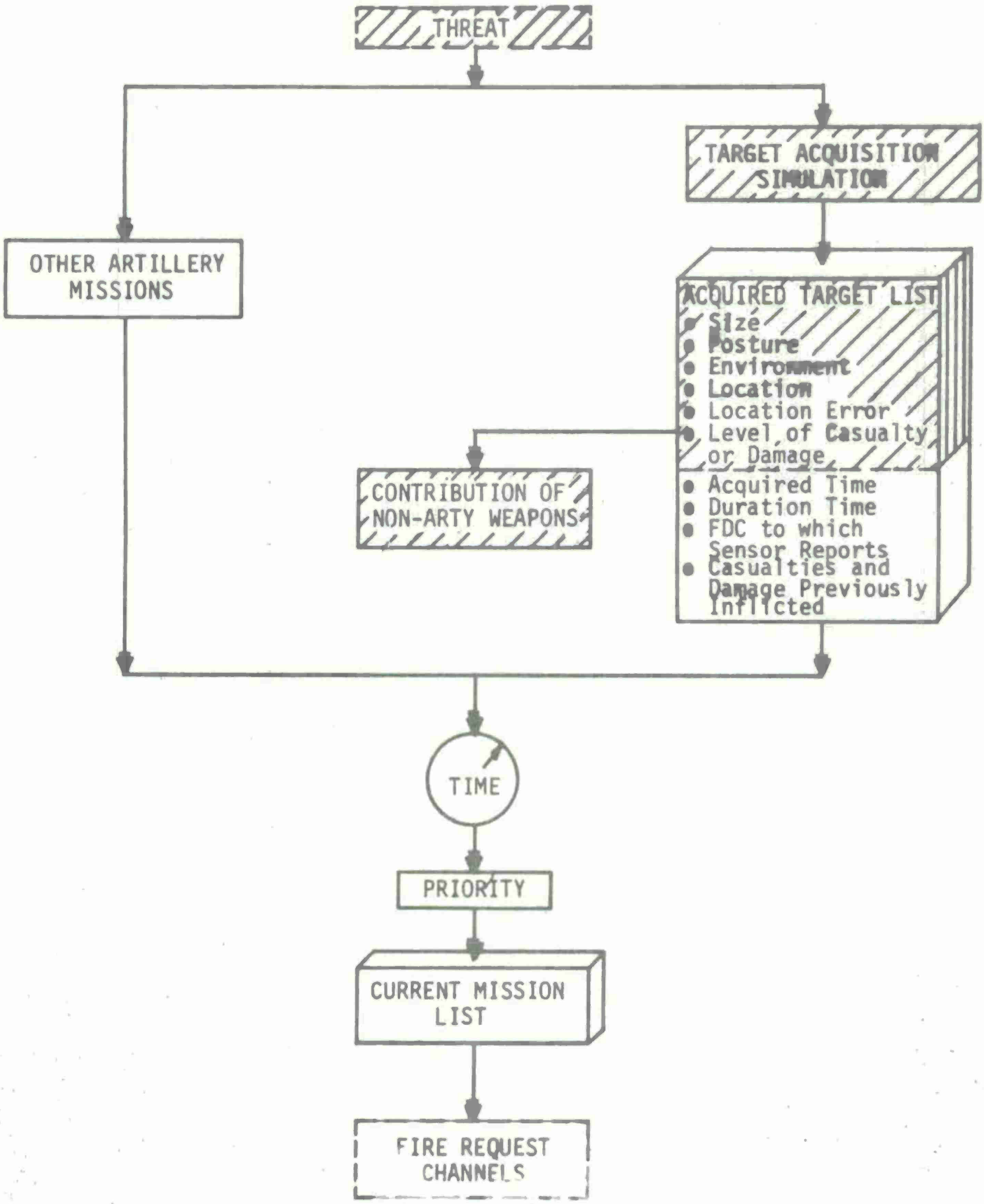


Figure 4. Firepower Requirements

ACQUIRED TARGET MISSIONS

PERSONNEL TARGETS

TANK TARGETS

APC TARGETS

OTHER ARTILLERY MISSIONS

FINAL PROTECTIVE FIRES

PREPARATORY FIRES

COUNTERPREPARATORY FIRES

BARRIER FIRES

SMOKE

ILLUMINATION

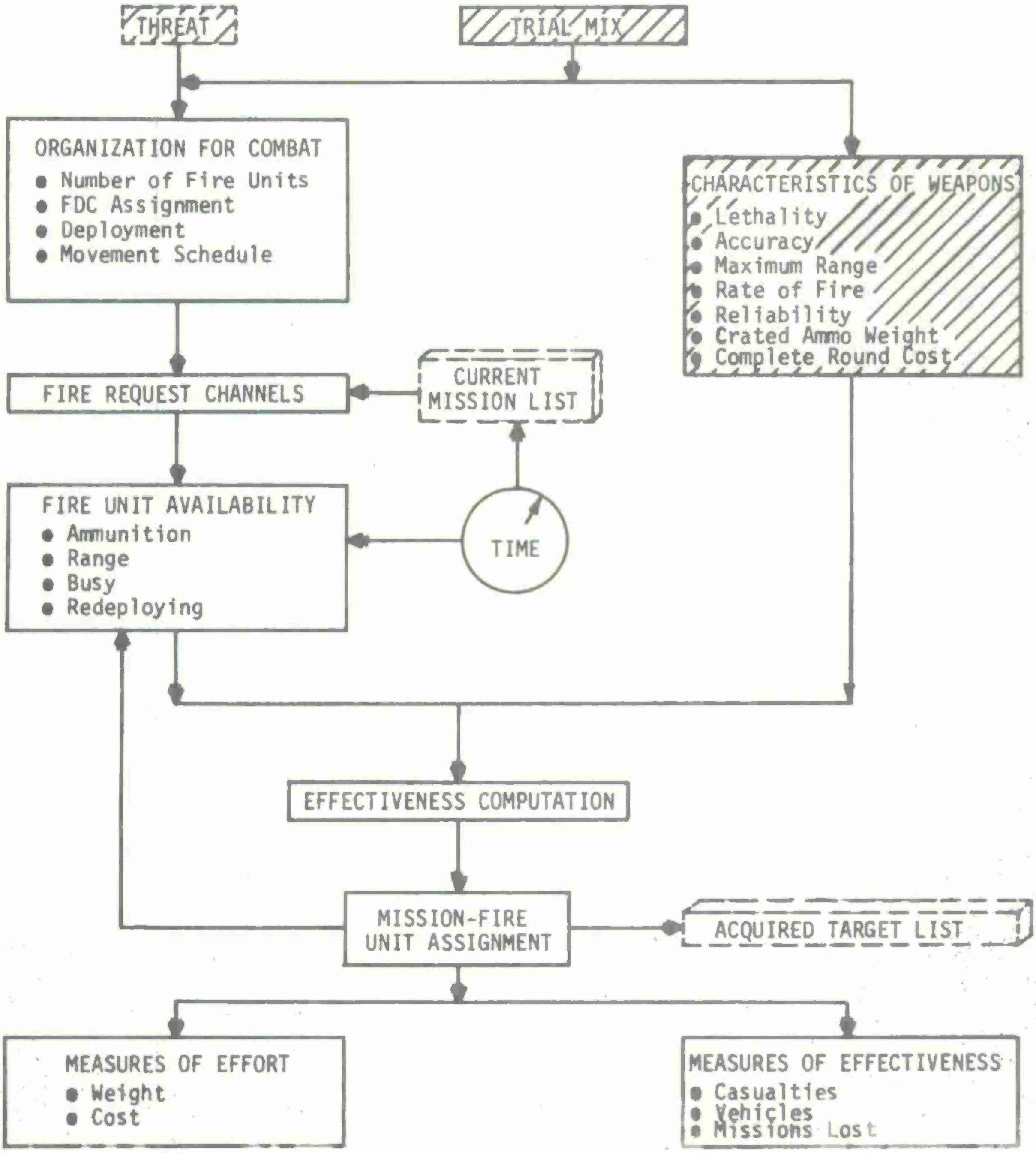
DESTRUCTION

SUSPECT TARGETS

HARASSMENT

INTERDICTION

Figure 5. Artillery Resources, Effectiveness Computation, and Mission Assignment



Automation in Contingency Resource Planning - The Contingency Readiness System

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Purpose

This paper presents an approach to determining critical implications for the design of a simulation model to support trade-off analyses of impacts on resource programs in order to develop management policies so that resource systems may respond effectively to changes in force plans. A computer system will be described which is the first generation effort toward the development of such a model.

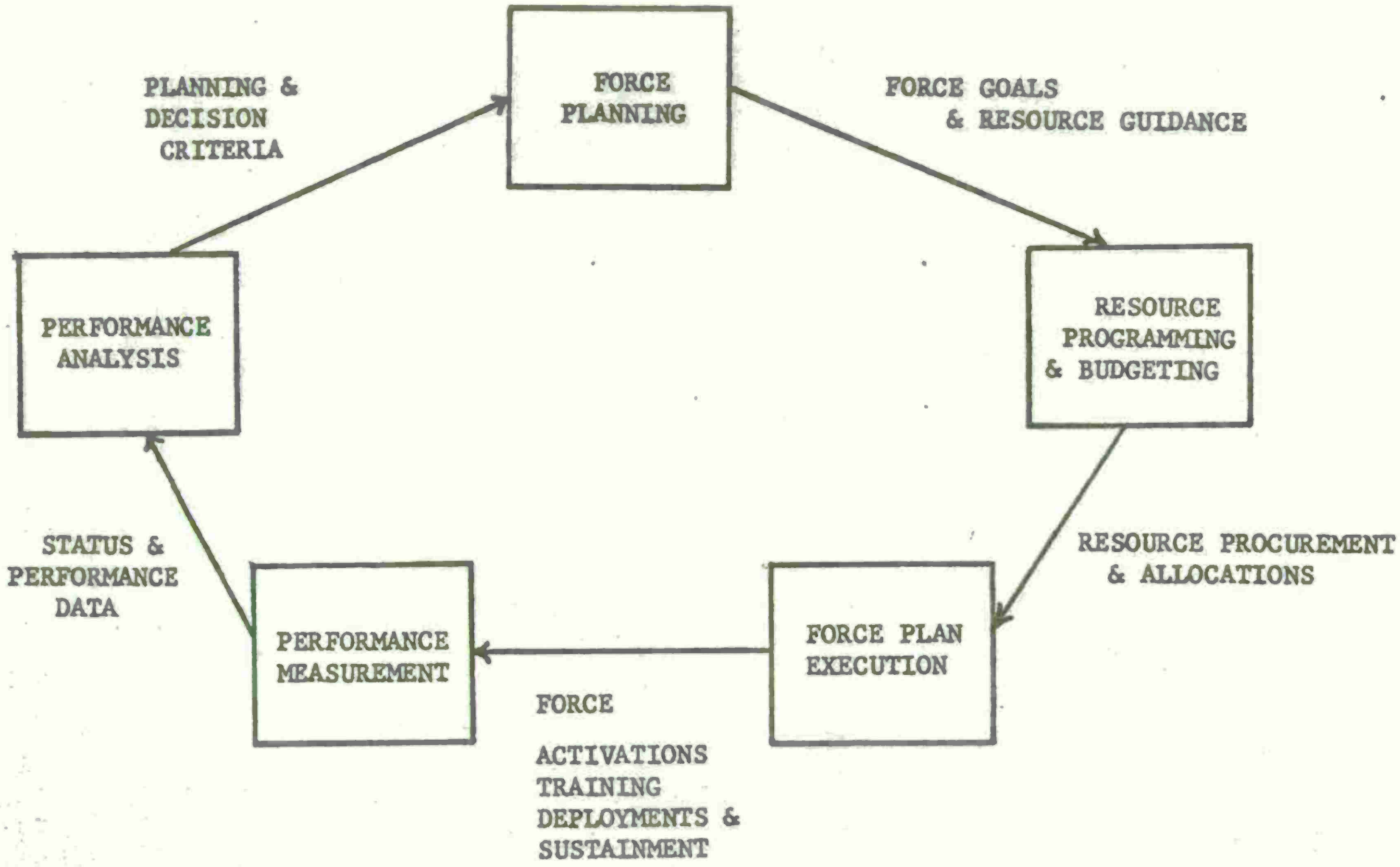
Background and Problem Development

The Contingency Readiness System (CONREDS) is an effort to improve resource planning by establishing a computer-assisted process of analysis. A model is needed to project impacts on resource programs of key management policy change decisions. Impacts projected for several change alternatives can be used to analyze trade-offs in order to choose the most effective alternative, and to formulate policy guidance to direct and control use of critical Army resources. The initial system operates in a rather narrow segment of the complex Army resource management process. A brief discussion of this process will help to focus on the segment of interest in perspective with the total.

One may view Army resource management as a feedback cycle. Figure 1 depicts this cycle from Headquarters, Department of Army (DA) viewpoint. In keeping with DA mission, the objective is to plan, provide, and sustain Army land force levels to meet demands for forces placed upon DA by unified and specified commands through the Joint Chiefs of Staff. CONREDS centers in the Analysis and Force Planning functions and, therefore, is directly concerned with status and performance data, planning and decision criteria, force goals, and resource policy guidance. Since the process is a cycle, the criteria and goals must relate directly to allocation of resources, execution of plans, and performance measurement and control. New goals are determined and policy guidance is needed when unprogrammed changes in the planned force require reassessment and redistribution of resources. Changes may be caused by deployments of contingency forces to meet actual threats or by changes in force plans and missions. In these situations, the loop is entered where status and performance data is available for analysis. The actual threat prescribes the scope of analysis. The analysis and planning system objectives are to predict the effect of necessary force goal changes, to determine the most efficient and effective

FIGURE 1

RESOURCE MANAGEMENT PROCESS



resource change alternative and to establish policy guidelines to execute the change in resource programs to accomplish the force goal.

Some history may be useful at this point. Soon after the Office of the Assistant Vice Chief of Staff was established in February 1967, work was undertaken by Management Information Systems Directorate to develop a model which would (1) assess the feasibility of force structure requirements, and (2) analyze the distribution of present and projected resource assets against these requirements in order to present the posture of a force which would be representative of the capability of that force to accomplish its mission.

A concept for a model was developed and proposed but was rejected as being too far removed from the actual procedure now being used by the Army Staff. It was felt that the results of proposed modeling techniques would not be accepted by top level decision makers because of a lack of confidence in the basic data and systems which would drive the model. In other words, there was no acceptable basis for establishing valid relationships needed to structure a simulation model.

At this point it was decided that a more pragmatic approach be taken with a view toward developing a model in phases starting with a very basic system which is assumed to be deterministic in nature. This system would be based upon current staff practice and would be gradually developed into a more sophisticated simulation. This approach has the benefit of improving basic data through use in a disciplined system, and of gaining a better understanding of the system entities and the nature of their interrelated attributes in order to develop representative simulation processes.

Attention was concentrated on the Army Capabilities Study which is the detailed process by which the Army staff plans the execution of force changes by scheduling resource assets to specific force units within commands. An in-depth review of the capabilities study process revealed the following:

1. Quick staff assessments of changes are inconclusive for providing definitive policy guidance for detailed studies.

2. The detailed studies require 60 - 90 days to complete.

3. Neither the design of the capabilities study nor the time allotted to complete a study allows for analysis of several alternatives.

4. Decisions rendered after initiation of a study often must be considered by the study, at the cost of considerable turbulence to the study effort.

5. The detailed process concentrates on personnel and equipment resources.

It was concluded that the most fruitful improvement would be in the policy guidance area, which precedes the detailed study. A system developed for this purpose would fill a gap in a "live" environment and would provide a quick payoff. Also, it would provide the "laboratory" for learning important cause and effect relationships for use in future developments.

Recognizing the complexity of the total problem, the scope was limited to selected equipment and personnel resource programs in order to provide a "quick'fix" prototype system using data sources and models already developed by the Staff. General system goals were then defined. First, the system must provide a more comprehensive but quicker response. This will provide more flexibility to the decision maker in the initial stage of the decision process. Secondly, and a corollary, the system must process a reasonable number of alternatives in the decision time frame. Lastly, information produced by the system must support the development of guidance parameters which are definitive and explicit enough for use in a detailed study.

Approach to Problem Resolution

The analysis of Army Capabilities Studies identified those data systems and models, either existing or being developed, useable for CONREDS. Figure 2 lists these with brief statements of capability. An hypothesis was formed based upon analysis of the systems and models, and upon consideration of the desired system capabilities. The hypothesis stated that by isolating key representative policy items which affect selected decision criteria (measures of effectiveness), maximum human analysis will produce essential policy decisions from information developed with a minimum data processing effort. The logical design of CONREDS was directed toward developing a system to test this hypothesis.

The existing data systems and models are used in CONREDS to:

1. Establish disciplined and compatible data bases for developing alternatives for comparison, and

2. Provide the internal design logic for developing projected impact information.

Essentially, the system will compute resource authorization requirements to support the force change, restructure available program data according to parameters, and present the computed values for selected decision criteria in formats to highlight important relationships which aid decisions.

The identification of key variables, decision criteria, and elements of information associated therewith, was determined using the

FIGURE 2

STAFF SYSTEMS & MODELS

Force Accounting System (FAS)	.. File of Army Force Units .. File of New Activations
The Army Authorization Document System (TAADS)	.. File of Unit Authorizations .. File of TDA Authorizations
Structure & Composition System (SACS)	.. Computes Item and Skill Requirements Based Upon FAS & TAADS Files. .. File of Basis of Issue Items
Personnel Inventory Analysis (PIA) Model	.. Projects Skill Assets .. Distributes Assets to Requirements by Force Element
Dynamic Rotational Flow Model (DYROM)	.. Projects Results of Tour Length Policy
Equipment Distribution Planning Study (EDPS)	.. Distributes Projected Item Assets to Requirements by Force Element

classical systems analysis approach. Based upon past and expected decision situations, the decision process was reconstructed, information needed to make the decision was determined, and a method was formulated to structure available data to produce elements of information which, through analysis, will produce the information needed to make the decision.

Policy guidance items used in detailed studies were examined and the following were chosen as key to the decision situation:

1. Distribution priority of force elements.

2. Percent level of fill of force elements.

3. Percent drawdown of equipment asset reserve stocks.

4. Percent authorization level of force elements.

5. Level and structure of forces, activation dates, and deployment dates.

6. Personnel tours length.

Policy guidance items are parameters for each alternative analyzed. Values for system variables are computed for each alternative by iterative runs of the system. Guidance items are assumed to be mutually exclusive. The first three affect the way available assets items are distributed to force requirements. The fourth and fifth items affect the number of asset items required. The last item effects required tour lengths for skills, grade substitution, and size of the skill development base.

Policy guidance is used deterministicly to calculate through time values of elements of information for certain decision criteria. The criteria together with explanations of the associated variable information elements follow:

1. Force Posture - expressed as critical averages and shortages of equipment items and personnel skills after redistribution of available assets to force elements.

2. Item and Skill Program Posture - expressed as percentage asset levels of total requirements for each item and skill included in the analysis.

3. Total Manpower Program - expressed as total required structure, trained, and end strengths; as the number and % of total manpower requirements over or short of total available assets; as the change in draft call required to support the change in force; and as a gross estimate of the change in program cost.

4. Total Equipment Program - expressed as a gross estimate of the change in program cost.

5. Skill Sustainment - expressed as % level of substitution, number of returnees and average base tour length, and number in the skill development base for each reported skill.

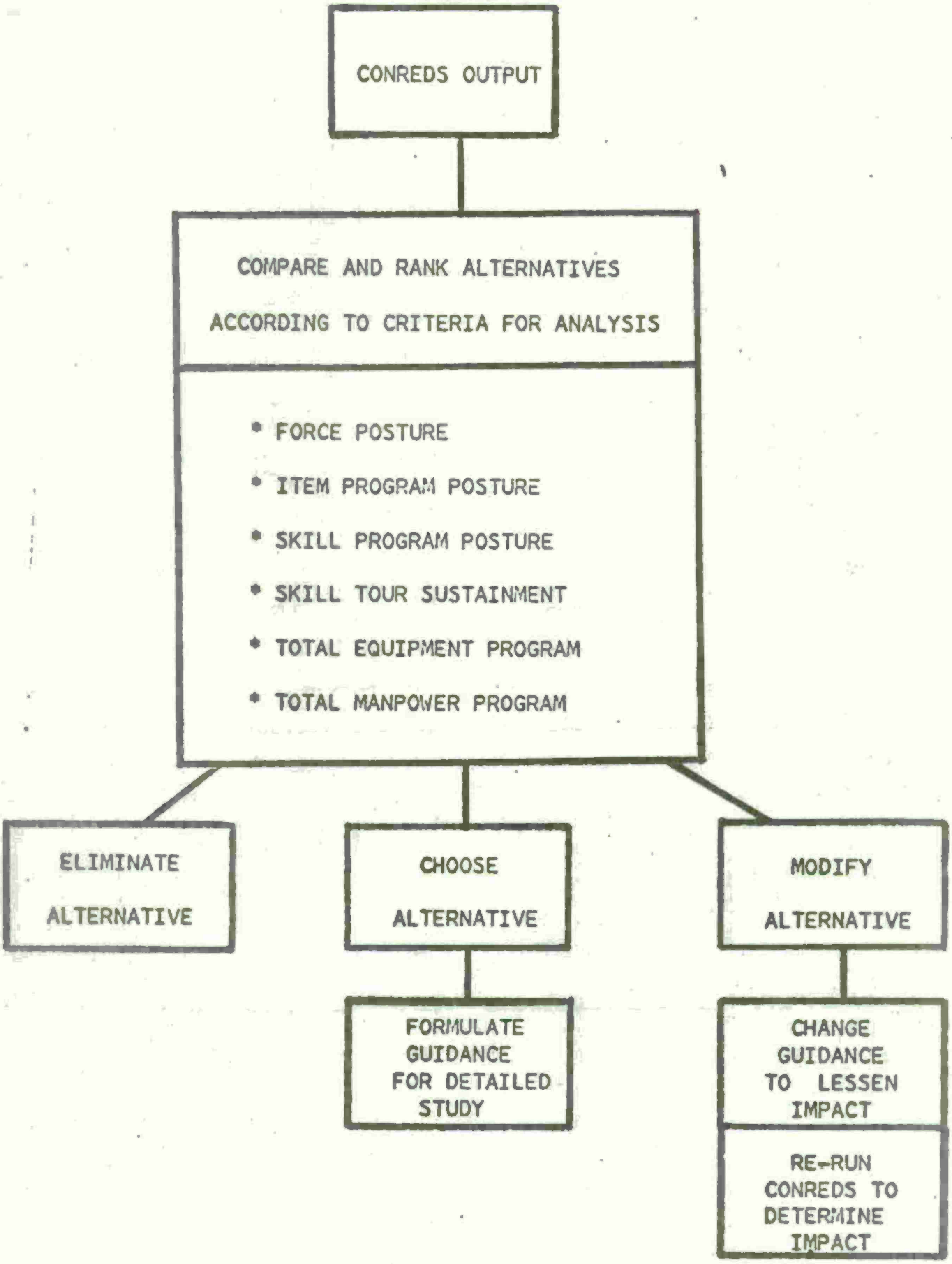
Impact information is developed for each of the first four criterion for both the present force and the changed force. For the first criterion, information is presented for the end of eight future quarters. For the remaining criteria, information is presented for the ends of fiscal years. The first criterion provides an indication of the effect the change in force will have on the overall readiness posture of the total force. All criteria are indicative of the ability of resource systems to support the change. The impacts associated with criteria are lessened or increased by manipulating the policy guidance parameters in subsequent system runs. These impacts are not precise, but are representative of the magnitude of the actual effect that would be caused by the change. In the decision process, therefore, impacts must be analyzed by the Staff to develop judgements of actual impacts. These judgements, then, are used to rank alternatives within each criterial set for the purpose of choosing that alternative with the least overall adverse impact on the force. After this elimination process, the favored alternative can be processed again through the system to further refine policy guidance items as required for the detailed capabilities study. Figure 3 depicts this staff analysis logic.

Basic Logic and Assumptions

Some simplifying logic and assumptions are employed in order to minimize the number of guidance items needed and to increase the analysis potential of information developed. Impacts are computed by subtracting asset levels from new requirements caused by changes in force levels. Approved program asset levels are held constant in the calculation of information for each alternative. This establishes a common base for comparison of several alternatives. Magnitude of impacts for each decision criterion permits ranking of alternatives in order of desirability. This logic permits the decision maker to assess the effect on force posture, after redistribution of available assets. He can determine if an acceptable situation is achieved before resorting to an increase in asset programs either by funding for additional procurement or by accelerating procurement. Impact information also permits manual cost effectiveness analyses to determine specific numbers of assets required and timing of procurements.

The following assumptions are fundamental to the computational logic of the system:

1. That all units and augmentations are activated and deployed at the dates specified in the force list. This means that the system does


CONREDS OUTPUT
COMPARE AND RANK ALTERNATIVES ACCORDING TO CRITERIA FOR ANALYSIS
• FORCE POSTURE
• ITEM PROGRAM POSTURE
• SKILL PROGRAM POSTURE
• SKILL TOUR SUSTAINMENT
• TOTAL EQUIPMENT PROGRAM
• TOTAL MANPOWER PROGRAM
ELIMINATE ALTERNATIVE
CHOOSE ALTERNATIVE
MODIFY ALTERNATIVE
FORMULATE GUIDANCE FOR DETAILED STUDY
CHANGE GUIDANCE TO LESSEN IMPACT
RE-RUN CONREDS TO DETERMINE IMPACT

not calculate changes in planned dates. This assumption follows logically from the fact that asset program levels are not changed. New scheduled dates must be based upon the availability of assets after the desired change in the asset program is determined. This assumption permits the system to isolate and articulate shortages (i.e. approximate number by command and total cost) which may preclude activations and deployments. The analyst can then concentrate attention on key shortages and recommend specific measures to correct this situation.

2. Secondly, that the intervening time appearing in the force list between activation of a unit and scheduled deployment of that unit is sufficient for training, maintenance, preparation for movement and movement to the assigned theater. This assumption permits abstraction from the primarily judgemental leadership aspects of force readiness measurement. This abstraction is made explicit by designating a time period within which these activities can be accomplished after the required personnel and equipment resources are made available. The time factors are set based upon a considered judgement of staff officers experienced in these matters. Time factors can be revised based upon the review and analysis of actual performance and readiness reports from field commands. Knowledge of these time factors together with CONREDS information displays allow the staff analyst to make judgements of the relative seriousness of resource imbalances and permits him to estimate an appropriate time range for planning allocation of a resource to units.

The logic and assumptions just described are exemplified by the following sample analysis of an element of information reported by CONREDS. The Equipment Distribution by Force display reports a shortage of 155 MM howitzers in RVN at 30 Jun 68. Knowing the distribution priority of RVN, that this is a deployment theater, and knowing the logic and assumptions of the system; the analyst can determine that this shortage probably will prevent the deployment of units, and will affect the activation and/or training and maintenance status of units in the quarter reported. The item itself gives him an idea of the relative importance of this shortage for the purposes of ranking the alternative being considered against the impacts of other alternatives. If this alternative is chosen, this information, together with a knowledge of production lead times permits the analyst to conclude that a slippage of units will or will not occur. The analyst can formulate precise guidance for the number and timing of additional assets required in the item program. A further analysis of the troop list can identify how many and what type units are affected by the shortage during the quarter. Slippage must occur when the production lead time extends beyond the requirement time. A similar analysis can be made for a personnel MOS.

Computation Processes and Data Development

The flow diagram in Figure 4 graphically depicts the system, enumerates the computations and shows the interface of machine computation and Staff analysts. The computations are simple and therefore are not described in detail in this paper. It is important to note however, that the basic data used in computations are developed using the systems and models

CONREDS GENERAL FLOW DIAGRAM

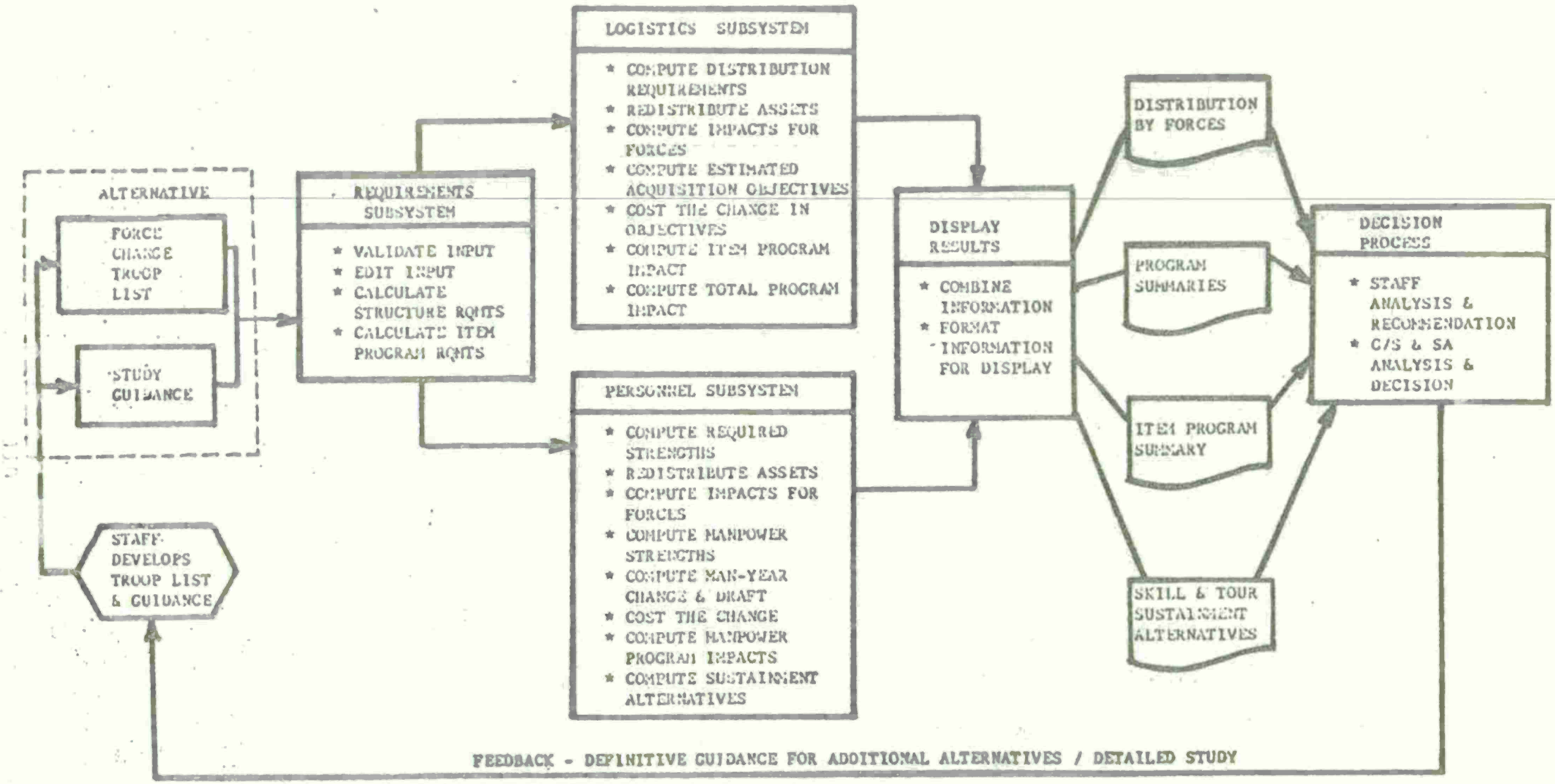


FIGURE 4

described earlier. Data bases for both equipment and personnel computations are developed using a single common force basis. This force basis is the programmed force in the Force Accounting System (FAS) which is updated periodically. This force basis is used in a Structure and Composition System (SACS) computation to develop numbers of items and skills using current authorization information contained in The Automated Authorization Document System (TAADS). Item and skill requirements are provided to DCSLOG and DCSPER for input to their planning systems for projecting resource assets to meet requirements. These asset projections are then used as the basic data for CONREDS computations. The data base development process is accomplished periodically by the Staff agencies. The data base development cycle is paced by the frequency of submission for asset inventory reports. The objective is to schedule the data development cycle in synchronization with asset reporting to take advantage of the most current asset data available to the Staff. The Staff uses information developed by the EDPS and PIA models for planning analysis. This same data will be the basis for CONREDS computations. CONREDS in effect presents the Staff a problem for analysis expressed in terms of their own planning information. Staff analysis of the information is oriented toward weighing the magnitude of the divergences from present plans to determine if these diversions are feasible and acceptable, and, if so, what is the most efficient and effective way to adjust to the new plan from the present planning base.

Summary Conclusions and Outlook

The approach to design of CONREDS centered on the hypothesis that information developed by applying selected key policy items to a decision situation will enable maximum staff analysis with minimum data processing effort. The gross abstraction must develop management information representative enough to support resource goals and policy decisions, which, when applied in the real world environment, will result in a predicted force posture.

To test this hypothesis, a simple partial model is being developed to address the complex problem area. This system is limited to selected management policies concerning major equipment items and personnel skills. The system will be used in live decision situations where a real need exists. Experience in this real world environment will provide information feedback to judge whether or not representative variables were chosen, and to gain a better understanding of cause and effect relationships. It is anticipated that use of this system will permit formulation of explicit relationships between changes in guidance and changes in impact, and between the guidance items themselves. Where valid relationships can be established, it may be feasible to compute values for system variables through time by a generative process. Further, the analysis may be extended to incorporate an assessment of projected readiness goals for units and commands. If this is accomplished, it may be possible to

establish valid relationships between changes in resource policy and resultant changes in force readiness. The model could be extended then to determine resource policy guidance, and procurement and distribution goals through time which would bring about the desired state of readiness at some future point in time. These goals would provide the basis for a control mechanism for use by resource managers in executing force plan objectives. As such, the goals must be explicit so as to be measureable, and readily translatable from force plan objectives to specific numbers of resources at specific times and places.

The prototype system will be completed shortly. Knowledge gained from an operational system will be used to expand the scope of the model to other resources and to other resource management policy decisions. In the immediate future the following areas are candidates for extention of the system:

1. Unit analysis for selected force elements (e.g. STRAF).

2. Projected readiness of selected units.

3. Distribution by Force Classification System force packages.

4. Additional items and skills.

5. Aviator analysis as a separate resource category.

6. Mobilization planning.

Future analysis will be directed toward expanding the model by including the following:

1. Supply and maintenance planning.

2. Transportation and LOC planning.

Concurrent with these extentions, cause and effect relationships will be identified and formulated for simulation, where possible, to assist in resource management policy decisions.

SIMULATION AND EVALUATION OF TACTICAL ROUTING METHODS FOR ARMY COMMUNICATIONS NETWORKS

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SUMMARY

A study is made of several alternate routing methods for the automatic processing of calls and messages in a tactical, all-digital, communications system. This paper presents a basic description, the outstanding features and some advantages and disadvantages of each routing method considered. A generalized discussion of computer simulation concepts and a computer simulation program for the evaluation and analysis of the routing methods are included.

Search, deterministic and combinations of search and deterministic routing methods are described. Hierarchial routing methods have been deliberately excluded as not being suitable for a tactical environment.

The ultimate objective is to achieve a comparative evaluation of performance of the various routing methods to different network configurations. The ability to extrapolate from a small to a large network, for economy and convenience, will be verified. The evaluation phase of the study will be accomplished by means of a large-scale digital computer simulation program, which, when completed, will be the largest of its type that is known to exist.

The compilation of data, analysis and evaluation of the routing methods described in this paper are to be discussed at length in a subsequent paper.

A. INTRODUCTION

The military communications system of the future must be highly flexible and expertly engineered with advanced automated techniques to ensure a capability to communicate regardless of the traffic volume and under the most extraordinary extremes of a tactical army environment. The system must be sufficiently comprehensive to permit an efficient flow of administrative and logistical traffic, that is mandatory and acute to a continuous effective state of combat readiness in any part of the world. A study of the state-of-the-art of routing technology for the automatic processing of calls and messages through a Tactical Army Communications System (TACS) resulted in a program to develop search, deterministic and combinations of search and deterministic routing methods. Hierarchial routing methods are not considered.

The vast complexities associated with manual analysis and evaluation of large communications networks extended the scope of the study to include a large-scale digital computer simulation program. Computer simulations, at a fraction of the actual system cost, will be used to verify design concepts, network efficiency and the variation of network parameters to assess the impact of different routing methods to different network configurations. This computer simulation program, when completed, will be the largest of its type that is known to exist. The programming language is FORTRAN IV and it is oriented to the IBM System 360.

The routing methods discussed are:

1. Saturation Signaling. A search technique which utilizes in-band message channels for propagating addressee signaling messages in locating a called party.

2. Real Time Method. This is a complete-path deterministic method whereby the call originating node selects a route to the destination node from a stored program or by use of a path finding algorithm.

3. One-Step Hybrid. A deterministic-search method in which a call is routed by the real time method if the addressee is within the originating node's "Area of Interest" or is routed by in-band saturation signaling if the addressee is outside the area of interest.

4. Out-of-Band Search A search technique that locates a called party over out-of-band channels utilizing the principles of saturation signaling The search is performed in discreet intervals or steps where by a predetermined number of nodes in the network are searched during each step. The total network is searched only on the last step.

5. Two-Step Hybrid A search-deterministic method by which the first step is to propagate the addressee signal by flooding the entire network over out-of-band channels to locate the called party and where the second step utilizes features of the real time method to establish a path between the origin and destination nodes.

Some preliminary evaluation criteria are: grade of service, network control, survivability, connection time, signaling and supervision, sensitivity to overloads, priority, conferencing, et cetera.

The field of computer systems simulation (particularly large computer system simulators) has undergone a tremendous transition over the last four or five years. As a result the computer system simulation has evolved as an entity with much promise. This evolvement and change in outlook, from the basic computer calculation program to the present dynamic entity has been brought about by several significant factors. The prime factor being the

ever increasing demands and vast cost of systems coupled with the complexities encountered in the development and implementation of these systems. The other factor being the development of large computer systems and the creation of computer languages making possible some of these simulations. As a result, computer simulations at a fraction of the actual system cost, to verify design concepts, system efficiency and variation of parameters appear quite feasible.

In contrast to the standard computer program which calculates and categorizes data from a programmed set of equations, the computer simulations and computer simulators discussed in this paper are quite different. These communications simulators are designed to simulate the five routing methods previously described with the associated military functions, typical of a tactical communications network.

The development of future tactical communications systems, the rapidly advancing state-of-the-art and new demands on the communications environment have changed previous concepts and configurations considerably. As a result, present communications using frequency division multiplexed (FDM) techniques are outdated with respect to the envisioned digital communications links between communications switching centers (SC). The digital systems provide system security, higher operating rates, and process on the links between SC's intermixed or mulitplexed traffic. This traffic would be comprised of digital voice, teletype, facsimile and other data. What routing doctrine is to be employed or link size used including network configuration, particularly during periods of congestion and stress, on these new networks, are questions that must be answered beforehand if the communications model is to operate efficiently and survive. Simulation should reveal some indication of a method or direction to pursue which appears promising as providing a solution to the routing problem. It is this type of information that can be obtained through computer simulation without actually implementing the system.

This paper is limited to a basic description of the various automatic alternate routing methods as defined, their outstanding features, some advantages and disadvantages of each and a generalized description of a computer simulation program which is to be used in their analysis and evaluation.

The results of the comprehensive simulation effort and a comparative evaluation of the different routing methods are topics for discussion in a subsequent paper.

B. SATURATION SIGNALING

The term "saturation signaling" per se refers to a method used in locating a called party. When a trunk call is placed in a network, the address is propagated on one path in every available outward direction.

This process is repeated at tandem switching centers until the destination center is reached. The called address is repeatedly sent by the originating center rather than being independently regenerated at the tandem centers. This latter procedure lessens the chance of error and precludes the need for tandem centers to request retransmission if the address is not received clearly. When the destination center receives the call, it repeatedly sends a lock-in signal back over the incoming path to the next preceding center which causes any redundant paths to be released. This center in turn "cuts through" (establishes connection between incoming and outgoing trunks), permitting the lock-in signal to progress backward to the next preceding center which releases any redundant paths associated therewith and establishes this connection. This procedure is repeated through the network until the lock-in signal reaches the calling center over the established path. The calling center then sends a lock-in verification signal over the established path to the destination center which terminates transmission of the lock-in signal and sends ring tone to the called party. In all cases, the lock-in procedure includes the release of redundant paths and termination of the search mode.

Relative to a given call, a center is considered to be in the search mode during the time that a connection is being set up. The search mode begins at the initiation of a call and ends depending on whether the switching center involved is operating as an originating, tandem or terminating center.

For an originating center, the search mode ends after the lock-in signal is received, the verification of lock-in is returned and the lock-in signal ceases. In case of a call to an unassigned number the cut-through mode will never exist since the search will end when all outgoing trunks are released.

In the tandem case, the search mode will end as soon as the lock-in signal is received and the incoming and outgoing trunks are connected together, thus allowing the lock-in signal to propagate toward the originating office.

At the terminating center, the search mode is defined to end after (1) lock-in signal has been returned, (2) the verification signal has been received and caused cut-off of lock-in signal, and (3) after the cessation of the verification signal.

The cut-through mode is defined to start at the end of the search mode and exists until the connection is released.

Some of the important or main features of the saturation signaling system are:

1. There is no central control of the network.
2. The system offers a unique address for each destination.
3. A calling party does not need to know the location of the called party in the system.

4. A call spreads through the system, over all available paths, from node to node until it reaches its destination at which time redundant paths are released and further spreading of the call is prevented.
5. The available route which requires the least amount of connection time is automatically selected.
6. Only one trunk in each trunk group is seized in setting up a connection.
7. The switching centers are not required to store network status information.
8. The switching centers are of standard design and structure and the saturation signaling technique is compatible with high speed switching; there is two-way utilization of trunks.

Some advantages and disadvantages of the saturation signaling system are:

1. Each switching center has access to the whole network, and does not require the use of the central offices or trunk lines.
2. The system does not require the use of directories.
3. Complex routing doctrines are not required.
4. System performance is essentially independent of the network configuration or connectivity.
5. The system is vulnerable to overloading.
6. Approximately two-thirds of all traffic may be search traffic.
7. The system cannot detect the movement or destruction of other switching centers.

Switching center functions may be generally summarized as follows:

1. Store identification of each call
2. Determine disposition of call -- "am I handling it"
3. Send call in all outgoing directions except on incoming line
4. Determine if subscriber is local
5. Keep tab of which trunk group call came from
6. Receive and send release and lock-in
7. Keep a record of number of trunk groups over which release was received
8. Release redundant paths upon receipt of lock-in
9. Discontinue trial after secondary call attempt is known.

C. REAL TIME METHOD

In contrast to the saturation search method previously described, real time routing is classified as a deterministic system that predetermines the location of a called party and establishes a route based on such factors as: the location of the called party, network connectivity, link loading, quality of the transmission path, etc. A complete path to the called party is established by the originating node rather than on a nodal or link-by-link basis.

If, for some reason, it is not possible to implement this route an alternate route is computed. The number of alternate routes are dependent upon the network connectivity and the system design constraints as pertain to maximum path lengths.

Each node stores or maintains a complete network-wide directory, a Subscriber Code Translation Table, a Network Status Record and a route selection table. Paths are selected from the stored information or by means of a route-selection algorithm.

The route-selection algorithm finds a path from the origin to the destination node on a link-by-link basis along the most desirable path. The most desirable path is related to the number of links, path length, traffic volume, link capacity, et cetera, to the destination node. At each node, all outgoing links from which a path to the destination is known is interrogated and the next node added to the route will be selected from the most desirable path information. Decision making at each node tends to assure best-path selection. Should the route or path predetermined by the algorithm become blocked another route will be computed. Precautions are automatically exercised to prevent circulating paths or "ring-around-the-rosy" as well as calls shuttling back and forth between two nodes. The route-selection algorithm is used only when there exist no routes in the route table.

The directory at each node contains a listing of all subscribers in the network. Typical information includes telephone or terminal number and the identity of the node through which the subscriber can be reached. Typical information provided by the calling subscriber includes the number of the called party, call priority, type of call (voice, data, conference, etc.). The originating node accepts the information from the calling party, identifies the called node from the subscriber code translation table and interrogates the route table to find a path.

Primary, secondary and tertiary routes are stored in each route table which serves all frequently called nodes; the three fundamental routes are first attempted in this order. These routes attempt to maintain the same grade-of-service for each link. If all three routes prove to be undesirable, they will not be considered in the algorithm computation since the undesirable aspects will be automatically reflected in the routing matrix. The route table is updated when changes in the network tend to cause an intolerable unbalance of traffic distribution.

The network status record maintained at each node is used for shortest path computations. All status information is reported to every node in the network. The status messages are tagged with an origination time so that only the latest information is recorded in the status table. If the same status message arrives at a node via two links, at the same time, the one with the later time is recorded; if the report times are identical, only one is recorded. Messages with earlier report times are dropped - they are neither recorded nor relayed to other nodes. Significant changes, when

defined explicity, may be circulated by a special report. When a new node enters the network, it must initiate a request for complete status information, usually from its nearest neighbor. In the meantime, the status information relative to the new node is transmitted throughout the network. The network status record is essentially a recorded pattern of the connectivity of all nodes and links in the network. It includes the current availability of channels within each link.

The Subscriber Code Translation Table (SCTT) is used to convert a subscriber number into the node number of the switching center that serves the subscriber. The movement of transient subscribers will result in a change of each SCTT for that particular transient code number. The subscriber's number per se will not change. The SCTT and network status messages are circulated through the network on reserved channels; SCTT data is given first priority but not pre-emption capability. During initial set up, the signaling channels will be almost fully occupied with SCTT messages. During the initialization period, the first transmission from a node contains all information stored in its SCTT table. This data is transmitted to all nodes connected via direct links. All other status transmissions consist of updated information. Each node sends new information to adjacent nodes except the node from which it was received.

In processing a call, the originating node first consults its own directory to determine if the called party is a local one. If the called party is local, the call will be internally processed as follows: for a non-busy condition the call will be completed; for a busy condition the call is dropped if the call in progress is on an equal of higher priority; in the event of a higher priority the call in progress will be pre-empted and connections completed.

If the called party is not local, the route table is queried for first a primary route; should this route be blocked, the secondary and tertiary routes are checked for availability.

The connection will be completed when either one of the three primary routes permits, otherwise the algorithm will be used to compute a new route as previously described. A priority call will pre-empt any one of the three fundamental routes.

Some of the main features of the complete-path real-time routing doctrine are summarized as follows:

1. Each node has a subscriber code translation table that converts a subscriber number to the node number serving the subscriber.
2. Each node maintains complete network connectivity information including the availability of all channels in the network.
3. Each node stores a complete network-wide directory.

4. Movement of subscribers to an area with different switching centers requires that all subscriber code translation tables be updated.
5. The network status record is updated when nodes are added to or deleted from the network and when traffic varies from dense to very light volumes.
6. Each node maintains a route selection table for shortest path information. The routes are established on a link-by-link basis.
7. Network status and SCTT information are circulated using specific channels, on a time shared basis. SCTT data is given priority without pre-emption capability.
8. Messages are tagged to prevent ring-around-the-rosy or shuttling.
9. The routing procedure is based on best available current status information - no alternate routing per se.
10. Frequent route computation tends to assure an excellent grade of service.
11. New nodes entering the network must initiate a request for complete status information.
12. The probability of blocked calls is dependent upon the frequency of new path computations and network changes.

Some problem areas could be mentioned as follows:

1. Large storage requirements
2. Initial development of routing tables
3. Learning of addition of new nodes and links
4. Adaptation to change of traffic demands
5. Long fade out time, downtime, etc.

D. ONE-STEP HYBRID

The one-step hybrid method is one which utilizes the features of both saturation signaling and real-time routing methods as previously described. This is accomplished by subdividing the complete network into different areas or segments. Real time routing is employed for locating a called party within a prescribed area and saturation signaling or search routing is used to locate a called party outside this area. This method seemingly has, as a basic intrinsic feature, a reduction in size of core memory capacity per node since each node only stores status information pertinent to a limited number of nodes. However, the rules of operation pertinent to the real time method in circulating network status information still apply, i.e., network status information must be transmitted to all nodes in the network.

An "area" is an entity that must be defined by the communications system controller. From a geographical and tactical operational viewpoint, it is unrealistic to assume that a network can be pre-divided into such particular areas of interest.

The one-step hybrid method assumes that an area is defined with respect to a reference node and contain all nodes N links or less away from reference node. In actuality, the upper limit of N is restricted to the predetermined or built-in capacity of core memory per node. Refer to the real time system description for information that must be stored at each node.

In general, each node will maintain a subscriber directory for subscribers within its area. Upon receipt of a call, the originating node will consult its directory for identification of the called party. If the called node is identified, the real time routing procedure will be followed in establishing a connection to the called party; if not, the saturation signaling method will be used.

The rules of operation for the one-step hybrid system are, for all practical purposes, identical to those applicable to the real time and saturation signaling methods. Nevertheless, a brief summary indicates the following highlites:

1. Considering the aspects of a systems controller, it appears necessary that network status information be circulated through the entire network. This does not effect a reduction in core memory for the network status tables.
2. A usage table is added to detect frequently called nodes within an area. This table will be used in conjunction with the other tables to assess the need for rearranging the nodal area configuration.
3. This method contemplates that an area configuration and its constraints are determined by a systems controller.
4. Each node will contain a subscriber code translation table only for those subscribers within its defined area. Entry data is the same as for the real time method.
5. When a new subscriber enters or leaves the network the identity or new location must be circulated throughout the complete network.
6. Circulation of status information is accomplished in the same manner as in the real time system.
7. The one-step hybrid system pre-supposes that the saturation signaling method will be very seldom required because of the frequently called number concept.

E. TWO-STEP HYBRID

The two-step hybrid method utilizes a search procedure (network flooding) in locating a called party and the real time procedure in establishing a connection or selecting a route between the originating and destination nodes. The flooding technique permits each node to broadcast the signaling message to all adjacent nodes, thus, flooding the network, whereas, in normal

saturation signaling such a message is under the control of the originating node. The two-step hybrid permits a message to return to a station that had previously rejected it; however, certain precautions are exercised to prevent a message getting trapped in a closed loop -- ring-around-the-rosy. Also, separate channels are used for locating the called party and transmission of messages, while in normal saturation signaling, the same channels are used.

Each node in the network will be required to perform these minimum basic functions:

1. Originate or receive the search. If the call is local, the search is not originated.
2. Make an entry in the search-in-progress memory (SIPM), only if there is no previous entry.
3. Send acknowledge of receipt of search signal to the originating node or the node from which it was received.
4. Propagate the search on all outgoing links.
5. Determine if itself is a destination node and compute a route to the originating node, accordingly.
6. Clear the (SIPM) entry upon receipt of the search acknowledge signal over all links.

Some generalized characteristics of the two-step hybrid routing method are as follows:

1. The search-in-progress core memory (same as the B-memory in the description of the normal saturation signaling method) may be smaller in size since each node clears the SIPM entry upon receipt of the search acknowledge signal. This acknowledgement indicates that the search signal has been received and propagated outward to other nodes.
2. Unnecessary delays could be encountered due to a queue formation on the signaling channels and the time-out concept associated with each call; if a call is not completed within a predetermined time interval it is dropped from the network. Each node waits fro time-out, for each call, before updating or removing the entry from its call memory.
3. If the originating node receives more than one route, it will select the "best" route on a least cost basis.
4. The use of separate channels for signaling could result in more "locked-in" calls than there are message channels to process them; the calls will be lost under these conditions.
5. A complete-network subscriber directory is not required as in the normal real time system; however, the connectivity information will be required for route computation.

F. OUT-OF-BAND SEARCH

The out-of-band search method locates a called party in a manner similar to saturation signaling. Three significant differences are: (1) signaling is accomplished out-of-band; (2) the search process is accomplished

in discreet steps throughout the network; (3) redundant processing of a call is permitted at each node. Although signaling is accomplished on separate channels, lock-in is achieved on the message channels.

Since a large percentage of the search signals does not result in lock-in, the number of search calls generated are allowed to exceed the lock-in capacity of the message channels. This precludes the necessity of reserving a channel for each search call while concurrently offering a wider selection of lock-in paths. It is realized that lost calls are possible due to this oversell philosophy but it is assumed that the simplicity of operation versus a "few" lost calls will prove to be more advantageous relative to system implementation. In event that lock-in is attempted over an all-busy link, the path is discarded and a release signal sent back to the originating node.

This routing method employs the concept of a restricted search technique based on path cost and path length. Be definition, when a search call is received at an upper limit node, and the call is not local, the node will store the call in its SIPM and transmit an "unsatisfied restricted search" signal back to the origin node -- denoting that the first restriction, as defined by path cost and length, has been reached and the called party not located. The node will not propagate the signal further until so advised by the origin node.

Assuming that the unsatisfied restricted search signal has been received over all outgoing links or when a predetermined time interval has been exceeded since the first search step, the origin node will propagate a search-extnesion signal; this signal will update or extend the original search limits, thus, permitting the search call to be propagated to additional nodes in the network. Failure to receive lock-in during the restricted search steps will automatically result in unlimited searching of the entire network

Pre-emption is accomplished in-band so that search calls, out-of-band, will never be pre-empted due to higher priority calls. Lock-in signals use in-band message channels and will be subjected to pre-emptions. When a locked-in channel is pre-empted all associated channels for that path will be released and SIPM data discarded.

The various signals associated with the out-of-band search method are of sufficient interest to merit itemization as follows:

1. Search signals are used to locate a called subscriber.
2. Backward release signals for a rejected search branch.
3. A forward release signal is used to terminate searching.
4. A lock-in signal is used to seize message channels.
5. Unsatisfied lock-in/backward release signals are used when a locked-in link is pre-empted and when a lock-in reaches a node at which forward release has already occurred for a call.
6. Unsatisfied lock-in signal for incomplete call.

7. A busy/backward release signal for off-hook condition.
8. An additional busy signal, non-audible, to terminate search when the called party is found to be busy.
9. Unsatisfied restricted search signal to indicate that the search step limit has been reached.
10. Search-extension signal to start second search step.

G. SIMULATION CONCEPTS

One of the most important questions that can now be asked is, "what entities are to be simulated and at what level?" This is important for several reasons. First, in the complex process of writing a simulation program, objectives can be easily distorted with the end product serving little or no purpose. Second, the communications simulator can be made to function as a complete independent entity or nucleus performing the functions necessary to accomplish a simulation objective at several levels (battalion, division, corps, field army, etc.). As an alternative, the simulator can also be incorporated and developed as an integral part of a larger war gaming simulator, where the communications model is a part or a subroutine. In a war gaming or like simulator, the communications model is made to operate with other subroutines that take into account opposing enemy forces, unit mobility, armor, artillery, terrain, logistics, weather, and so on. In the former case (as an independent entity), the communications model is the focus of the simulation. In the war gaming case, the communications simulator plays an essential but somewhat of a secondary role and is a subroutine designed to test the impact and efficiency of a predetermined routing scheme whose doctrine is unaltered throughout the series of games. In the latter case, the communications simulator does not attempt nor does it simulate or decide which is the best type of routing doctrine (deterministic or non-deterministic) to be used despite the fact that it picks the best route in the network influenced by outages in the unique war exercise under simulation. In addition, any attempt to extrapolate information or generalize from a lower echelon communications system (battalion, division, . . .) to a higher echelon system such as a field army system may yield highly unrealistic results. Nothing has been said of the heterogeneous environment that may exist, e.g. the problem may be compounded by having different types of divisions such as armored, infantry, etc. Thus, designing the simulator to perform specific detailed functions and simulate various routing doctrines requires greater elaboration and a more comprehensive study of the problem.

One might now question the choice of the previously mentioned routing schemes for simulation, as there are a multitude of routing schemes to choose from. In order to develop the proper simulation tools as much problem definition as possible must be accomplished. As one of the objectives of this task is to study routing doctrines in tactical communications networks it would be highly desirable to establish the upper and

lower bounds in this area and at the same time have the capability to bound problems into even smaller sub-intervals. In this manner routing doctrine information, whether deterministic, undeterministic or hybrid, can be collected and compared against one another to develop trends and performance criteria. It is the intent of the doctrines chosen to provide these upper and lower bounds. It is imperative that as much problem definition as permits be undertaken. Once a simulator has been completed or a good part of it developed, it is extremely difficult, because of program interrelationships, to alter major segments. The alteration of one part will affect other subroutines. This is particularly true if the size of the program is large.

H. ORGANIZATION OF THE SIMULATOR

One module of the simulator is to provide or generate a predetermined amount of traffic (voice, data, or both) into a given network with its respective rules of operation. It is also used to record the statistics and tabulate them in some presentable form to the systems analysts. Optimization of the simulator occurs if the functions are accomplished and the simulator is divided in the following manner: input phase, simulation phase and output phase.

In a communications network, generation of calls, call interarrival time (call-distribution) and type of call etc. must be catalogued and inserted into the network before any experiment can begin. Thus, the input phase provides the proper insertion point and accomplishes those functions and objectives prior to the actual simulation. There are still other advantages in having an input phase. Many times throughout the course of a series of simulations runs, the same input conditions must prevail to test changes made in the simulation phase. A separate input and simulation phase permits this flexibility when changes are necessary only in one phase. Modularization of the program in this manner permits more efficient utilization of the available computer time (including time) by permitting each segment to run independently, eliminating reruns and rescheduling where otherwise two or three continuous hours for a non-modular program would be needed.

The simulation phase of the communications simulator will simulate the flow and processing of calls and document their progress through the system. The efficiency of the routing doctrine and versatility of the simulator will be revealed.

The purpose of the output phase is to record all of the events that have occurred in the previous stages. If the collected simulation statistics require statistical tests, it would be most efficient to have a separate output phase in which to process these parameters. If the collected results do not require elaborate time series statistics and test procedures, it would

be best to incorporate this stage with the simulation phase. There are inherent disadvantages in combining output and simulation phases. In the event the simulation phase is changed to increase its capability or expanded to larger communications networks, implementing these changes may require increased core memory thus necessitating separation of the simulation and output phase. The creation of an output phase provides the additional capability of control over the format including suppression of undesired statistics. The ability to vary the sampling period of the network under study so as to permit a detailed examination of the network if desired, should be included in the simulator. This soarse to fine grain analysis feature is very rewarding in the study of transient effects on the network. Caution must be exercised in choosing a sampling interval since too small an interval might be unwarranted (e.g. no change in network status) thus creating large volumes of repeated output data. On the other hand, too large a sampling interval will not record significant events that have occurred.

A statistical equilibrium test to determine when the simulator has reached specified traffic levels is most desirable. The simulator has included as a subroutine, a series of tests to measure predetermined traffic levels, suppressing statistical data prior to the initial equilibrium level. The ability to vary the voice and data traffic volumes and the holding time is also provided. It is to the advantage of the programmer and user to include diagnostic routines to detect errors throughout the program which the computer is unable to detect. Considerable time will be saved in debugging the program with the aid of these diagnostic routines.

I. DYNAMIC VERSUS STATIS SIMULATION

The words "dynamic" and "static" are often confusing and used rather loosely with respect to simulators, especially the word "dynamic". A statis simulation would refer, as the name implies, to the steady state case. In this state, all of the declared input parameters are constant throughout the simulation, where network stresses such as node outages are not introduced. These conditions can be considered the normal or ideal operating conditions. A dynamic simulator has the capability to simulate node outages, different network configurations and traffic volumes, etc. Thus, a simulator with dynamic capabilities in this sense is capable of stressing a network to test the routine doctrine and system efficiency. "Dynamic" can also refer to the capabilities of the simulator itself, independent of the routing doctrine used or system operation under test. A simulation program capable of declaring one set of input parameters and without interrupting the program during the course of the simulation, change the input parameters to other values or different network configurations is also a dynamic program. A dynamic simulation can also restore the initial or steady state conditions at some time after the transient effects were imparted on the system. In addition, features such that after a

particular run has been accomplished, if further statistics are required by the user from this run, the ability to continue this simulation from where one stopped, without going back to the beginning, can exist. Thus, in this sense, the program's dynamic capability is in terms of the flexibility it affords the user in evaluating the network. The simulators under development will be dynamic in every sense of the word.

J. LANGUAGE OF THE SIMULATOR

Several factors will determine the particular language in which the simulator is to be written. If the user had decided to use the computer facilities at his installation and the computer size and capability are deemed adequate, the choice of the simulation language has been narrowed down and defined to a considerable degree. If the user does not limit himself to any particular machine, he may take advantage of the many computers with increased capabilities affording maximum flexibility (to both the user and programmer) and simulation elasticity for future program expansion.

Many programmers will have a tendency to favor the simulation languages available. This is due to the fact that these languages perform many functions automatically and in parallel including collection and presentation of output statistics. Languages such as Jovial, Simscript, SOL, GSPP, etc., will automatically allocate storage, make use of partial word operations and will provide convenient notation for random events, among other desired features. While this is desirable and much programming time can be saved, there are certain deficiencies in these simulation languages which some users cannot accept, particularly when discussing the large network simulators discussed in the context of this report. Core memory, for one thing, may not be used as efficiently as it should be. Partial word operations are limited to certain discrete sizes (half-word, quarter-word, etc.). The diagnostic routines, statistical tests and formats available in the language do not necessarily provide the in-depth information required. The output statistics available are general and do not provide the structured details or formats required in these elaborate simulations. An examination of existing compilers and their capabilities must be made if the simulation is required to perform on more than one type of computer. This aspect can be a very influential factor in the choice of a simulation language. If a simulation is to be custom made to simulate a special system, maximum use of memory packing should be made. The previous factors will determine what simulation language is to be chosen.

There is no set manner of organizing the different phases of a simulator. It can have as little as two stages (input and simulation) or complex with the creation of additional stages between the input/simulation and/or simulation/output stages. Organizational blocks will be dictated by the complexities involved, in depth details desired, the languages to be used and output statistics collected.

K. CONCLUSIONS

A lack of knowledge of system characteristics and experimental data is a major lacuna in the art of planning a large-scale tactical communications system. Hundreds of concepts and theories concerning call and message routing have been postulated and still others are being developed. Are these theories interrelated? Is one more powerful than the other in a true practical sense? Existing theories encompass only a small portion of future tactical systems and there are no known analytical techniques that are sufficiently comprehensive to solve the associated problems. Hence, many investigators have focused their attention to large and small scale digital computer simulations. It is envisioned that many of the perennial questions concerning tactical communications networks will be reasonably answered with a considerably high degree of confidence through continued aggressive computer simulations utilizing more realistic input criteria.

It is intended to show how one routing method compares with another under normal and extreme conditions, for different network configurations, in a subsequent paper. Grade-of-service will be the main factor in this comparative evaluation.

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OPERATIONS RESEARCH/SYSTEMS ANALYSIS
WHAT ARE THEY?

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The letter of guidance to this panel contained the following sentences:

> "Since there seems to be, among various people throughout the Army, a confusion about the meaning of the terms and how they actually apply to military problems, the Planning Committee has decided to hold a panel discussion with the tentative title, 'Operations Research/ Systems Analysis - What Are They?' It is hoped that in this session you and your panel participants will discuss this problem and come up with some <u>definitive</u> terms regarding each of them."

The implication here seems to be that if we had better definitions somehow the confusion would be dispelled and all would understand the nature of Operations Research and Systems Analysis. This hope I fear is vain! To use an analogy, let us consider for a moment the subject of mathematics. Mathematics, as a discipline, is more than two thousand years old. All of us have been exposed to at least some of its branches and are aware of its utility. In spite of this familiarity, how many of us would attempt a definition? I doubt that many professional mathematicians would undertake the task. In 1941, Professors Courant and Robbins published a book with the intriguing title, "What is Mathematics?" No definition is given in the text. Four pages are devoted to philosophical

discussion of the nature of the development of the discipline and to the dangers inherent in some oversimplified definitions concluding with the following paragraph:

> "Fortunately, creative minds forget dogmatic philosophical beliefs whenever adherence to them would impede constructive achievement. For scholars and laymen alike it is not philosophy but active experience in mathematics itself that alone can answer the question: What is mathematics?"

Following this paragraph are 510 pages of charming and illuminating discourse on mathematical subjects which do indeed leave the persistent reader with an understanding of what mathematics is about. As far as I am aware, no reviewer has ever commented on the lack of a definition.

This discussion is not a prelude to proposing a 500-page definition of systems analysis or operations research. It is intended only to make the point that disciplines with substantial content and broad application are unlikely to be completely or satisfactorily described by short definitions. However, such definitions seem to be desired, and can be informative and even useful in spite of their shortcomings.

In spite of the relative youthfulness as disciplines of operations research and systems analysis, there is rather extensive literature associated with them, and there is certainly no shortage of definitions. In the following we will consider some of these definitions in the hope that the comparison will shed some light on the subject matter. Operations research and systems analysis will be discussed separately to conform with convention, although it is my personal opinion that they represent overlapping areas of application

of the same discipline. This opinion is to some extent supported by the view expressed by C. J. Hitch in the following quote:

> "Both operations analysis and systems analysis are attempts to apply scientific methods to important problems of military decision. Both have the same essential elements:
>
> An objective, or a number of objectives.
>
> Alternative means (or systems) by which the objective may be accomplished. (These may be different weapon systems, or different strategies of using a weapon system.)
>
> A mathematical or logical model or models; that is, a set of relationships among the objectives, the alternative means of achieving them, the environment, and the resources.
>
> A criterion for choosing the preferred alternative. The criterion usually relates the objectives and the costs in some manner, for example, by maximizing the achievement of objectives for some assumed or given budget."

The distinction between operations research and systems analysis has been presented by E. R. Quade in the Rand publication, Analysis for Military Decisions, edited by E. R. Quade. Much of the Introduction is devoted to this point. The following paragraph taken from that Introduction summarizes his view:

> "In a sense, the main difference between systems analysis and operations research may well lie just in emphasis. A good deal of the earlier work tended to emphasize the mathematical

models and optimization techniques. Honors went to practitioners who used or improved mathematical techniques like linear programming or queuing theory and found new applications for them. These people were usually associated with decisionmakers who knew what their objectives were and how to compute their costs, largely in terms of some single, clear-cut criterion. On the other hand, systems analysis -- while it does make use of much of the same mathematics -- is associated with that class of problems where the difficulty lies in deciding what ought to be done -- not simply how to do it -- and honors go to people who have the ability or good fortune simply to find out what the problem is. The total analysis is thus likely to be a more complex and less neat and tidy procedure, one seldom suitable for quantitative optimization. In fact, the process is to a large extent synthesis; the environment will have to be forecast, the alternatives designed, and the operational laws invented. Thus, with systems analysis, one associates 'broad', 'long range', 'high level', 'choice-of-objectives' problems, and 'choice of a strategy', 'judgment', 'qualitative', and 'assistance to logical thinking'. In contrast, with operations research one associates 'lower level', 'overall maximization', 'mensuration', 'quantitative', 'means-to-an-end', and 'optimal solution'."

The distinction is fairly drawn if one admits the validity of the implied definition of operations research as being primarily concerned with mathematical models and optimization techniques. While it is certainly true that the Journal of the Operations Research Society may give this impression, it is not necessarily true that the Journal's publication accurately or even approximately reflects the activities of its membership. We are all aware of the fact that much of what is done is not publishable; due either to security regulations or to the sponsor's

wishes. From a major project it may be possible to publish only a small analysis performed to support the effort but not in any sense a major part of it. Thus considerable distortion is introduced into any attempt to relate what operations researchers do to what they publish. One might also mention that editorial policies certainly have more influence on what is published than they have on what is accomplished, but that is another subject for another day.

The main point here is that responsible operations researchers, no less than systems analysts, regard their principal functions as finding the right problem rather than simply finding new applications for classroom techniques, or extending those techniques to handle more general problems. The latter may be fun, but generally speaking, it is more likely to be mathematics than operations research. The distinction that Quade draws between high-level vs. low-level, qualitative vs. quantitative, etc., in comparing systems analysis and operations research certainly has some foundation. The adoption of the term "systems analysis" by the Office of the Secretary of Defense, while the term "operations research" was in use in the Army, would of necessity lead to the distinction. The parallel distinction has not, to the best of my knowledge, been widely adopted in the industrial community.

Turning now to the question of what is operations research we note that, whatever it is, it is known in the government, industrial, and academic communities. Within the government it is recognized by the existence of a number of operations research groups and the existence of a civil service classification (Operations Research Analyst). The situation is comparable in industry where operations research analysts are employed both in "in-house" groups and as consultants. Within the academic community we find both graduate and undergraduate courses offered in operations research. A number

of universities offer degrees in operations research and a number of more classical degrees offer an OR option. The professional status of operations research is further enhanced by the existence of both a national and an international professional society providing meetings and periodicals to meet the needs of their members.

The preceding comments would appear to imply that operations research is a fairly well established discipline or profession. There appears to be a commonly accepted collection of methods and techniques that are assumed to be known by its practitioners as well as areas of specialization as is common in other professions. To fairly characterize the discipline in a short definition is, as we stated earlier, probably impossible. However, a number of creditable attempts have been made, some of which will be discussed here.

The Army Dictionary defines OR as:

> "The analytical study of military problems undertaken to provide responsible commanders and staff agencies with a scientific basis for decision or action to improve military operations. Also known as operational research, operations analysis."

This definition is a little restrictive in the sense that military operations may not be interpreted in a broad enough sense to include many of the systems that are actually studied by operations researchers employed by the military. Further, the definition does not make clear that while OR provides a basis for the decision or action, it is not the <u>only</u> basis.

There are a number of definitions of similar type. They all seem to have a number of things in common. If I might skip over the definitions

and just go to their commonality, they seem to share the following properties. The attack on the problem is to be analytic or scientific in method or spirit, the aim is to assist a decision maker in choosing a course of action and that the decision is concerned with some kind of operation under the decision-maker's control. The differences in the definitions appear to be largely a matter of orientation and application.

Systems analysis as a term to describe the use of analysis to aid military decisions has, according to Hitch, been used to describe analyses immensely more complex than those World War II analyses that were the beginnings of operations research. The Army Dictionary defines systems analysis as:

> "An orderly study of a management system or an operating system using the techniques of management analysis, operations research, industrial engineering, or other methods to evaluate the effectiveness with which missions are accomplished and to recommend improvements."

AFT 173-1 provides the following definition:

> "Systems analysis is the methodical examination of alternatives in terms of both quantitative and qualitative estimates of costs, other resources, and benefits. Its objective is to evaluate the over-all technical, operational, and resource implications of alternative courses of action."

For a final definition we return to Quade:

> "Systems analysis might be defined as inquiry to aid a decisionmaker in choosing a course of action

> by systematically investigating his proper objectives, comparing quantitatively where possible the costs, effectiveness, and risks associated with the alternative policies or strategies for achieving them, and formulating additional alternatives if those examined are found wanting."

From these definitions it is clear that systems analysis includes cost-effectiveness studies. In fact, there are published definitions equating the two. From the Army Dictionary definition, systems analysis includes operations research. This point of view is consistent with that of Hitch who observed that they were comprised of the same basic elements. The differences between the definitions of systems analysis and operations research seem to be mainly, as Quade has pointed out, a matter of emphasis. The most significant difference in the definitions is the emphasis on scientific method in the OR definitions to describe the attack on the problem, whereas in SA the emphasis is on methodical, orderly inquiry. But here I think the OR definitions are defective in that they claim more than is practiced. It would seem that more often than not it is the spirit of scientific inquiry that is brought to bear on the problems rather than the scientific method. While the latter may be preferable, we are just not always in a position to avail ourselves of its blessings.

Granted this point, it seems to me that as the differences between SA and OR become negligible, they appear to be applications of the same discipline at different levels of command. This suggests that a common definition could serve to describe them. With full knowledge of the fate awaiting one guilty of such folly, I will propose here such a definition. It is quite similar to the definition used in the Haines Board Report. No claim to originality is made -- the definition is simply a composite -- it suffers from the deficiencies

of all short descriptions of large subjects. It is proffered mostly in the hope of stimulating the kind of discussion that may result in furthering the objectives of the panel. That is enough apology, here is the definition:

> Operations research/systems analysis is that discipline concerned with applying both the spirit and methods of scientific inquiry to provide decision makers with an analysis of the available alternatives for structuring or operating complex systems. Its principle tool is objective, analytical and disciplined thought, supplemented by mathematical, statistical, and economic techniques where relevant and applicable. OR/SA provides a tool to the executive, complementing the qualitative and subjective factors on which decisions must be based.

OPERATIONS RESEARCH/SYSTEMS ANALYSIS
WHAT ARE THEY?

Dr. Philip H. Lowry
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I am not certain how useful it is to define Operations Research or Systems Analysis. Perhaps the clearest but most useless definition is that Operations Research and Systems Analysis are what people do who call themselves Operations Researchers and Systems Analysts.

I am also not certain whether there is a significant or useful distinction between Operations Research and Systems Analysis. It is more a matter of emphasis; a matter of the kinds of decisions at issue. It has been said that Operations Research is Systems Analysis carried out by the Deputy Undersecretary of the Army for Operations Research--mainly by physicists. Systems Analysis, on the other hand, is Operations Research carried out by the Assistant Secretary of Defense (Systems Analysis)--mainly by economists. There are other definitions. Operations Analysis differs from Operations Research because it is carried out for the Air Force rather than the Army. Until quite recently, the Navy was concerned with Operations Evaluation, not Operations Research. Now, of course, the Navy has a Systems Analysis Office.

The important thing is that our profession is a rapidly evolving one. It is quite different from what it was five years ago and, hopefully, it will be quite different five years from now. Consequently, the best way to understand what it is may be to review what it has been over the past 30 years.

Before beginning the review, I think it is important to state clearly what Operations Research/Systems Analysis is not. Since this is a

military operations research symposium, I will use military examples and military terminology to define what I think it is not.

There are three things that OR/SA cannot do: analyze personalities, select the degree of risk in a solution, and select criteria for evaluation.

I am sure all of us have been asked how we deal with leadership, command, cowardice--all of the things that concern an individual, a single personality. The simple fact is that we cannot deal with them. As Operations Analysts, we must deal with statistical aggregates. Since we are normally assigned to problems concerning all or a large section of the Army, our inability to deal with leadership is not critical. We study organizations, weapons, tactics to be carried out by average soldiers. Data from past wars, maneuvers, tests provide us the basis for dealing with averages or distributions. It also provides us an argument to counter the tendency to use extreme values. People remember the unusual so that combat capabilities, in war stories, have U-shaped distributions. It is my experience that actual combat capabilities are normally distributed.

Another thing that OR/SA cannot do is select the degree of risk that is acceptable. One problem, if we look at it in game theoretic terms, is the sharpness of maximum or optimum strategy. There is a subjective judgment that every decision-maker must make as to how "sloppy" an optimum he must have since we are always dealing with an uncertain future and an incompletely known past. We have all found cases, I am sure, where we have found extremely sharp optima, which means that any significant change in the inputs makes the "optimum" strategy much worse than its neighbors. We do not have a technique for finding slightly lower optima where it

doesn't matter how close we are as long as we are in the ball park. So, the selection of risk is not an output but an input to operations research.

The third thing that OR/SA cannot do is select criteria for evaluation. The selection process is not, itself, scientific, yet it is something that all scientists must do, whatever their field. Hence, operations analysts should be the ones to select the criteria but they should realize that the selection process is an art and not a science. It is also the role of the operations researcher not to lock himself into a single set of criteria. He must consider alternative criteria and extend the concept of a sensitivity analysis from mere number-manipulation to a consideration of alternative concepts underlying the numbers. For example, many sensitivity analyses of weapon mixes have been made of the numbers assigned to detection probabilities in target arrays; but few analyses have been made of the effect on weapon mixes of changing the criteria from the number of targets destroyed to the reduction in friendly casualties occasioned by the support fire.

Back to the evolution of Operations Research. I think three elements have characterized OR/SA in the last 30 years. One is the reduction in sub-optimization. We have become a little more ambitious as time has gone on; we have tried to solve large problems. If we have not always succeeded, the effort has helped us solve problems larger than before.

The second element is the non-quantitative factor. This, I think, is of growing importance, particularly for the Army.

Finally, there is the shifting allegiance of Operations Research in terms of the kinds of people who want it. Originally, the users were operators. Then, we had a period where it was mostly in R & D. And today it is often managers

So, for the remainder of my time, I want to talk about Operations Research on current operations, Operations Research on future operations or R & D. and Operations Research to help management.

Reduction in Sub-Optimization

In the earliest days, Operations Research in the Army tended to deal with weapons in terms of hits, kills, lethal areas, target hardness, and, in general, with the interaction of a single projectile and its target. The criteria were almost exclusively in terms of hit or kill probabilities. The problems were mostly choice problems: is candidate A better than candidate B?

There were a few exceptions to this narrow approach. The most notable exception was the VISTA REPORT of 1951. I would very much recommend that those of you who have the opportunity read this report. Its approach to problems, the problems themselves, and its solutions are quite contemporary in tone.

The second stage in the reduction of sub-optimization came during the Korean War. A specific piece of hardware was regarded as imbedded in a system, a system where many pieces interacted and all had an effect on the result. The earliest Army example I can find was the first NIKE studies made in 1951 or 1952,where it was recognized that the radar as well as the missile had to be taken into account. Still later, the concept of system expanded to take account of the interaction of several batteries or battalions and command-control became part of the system. As far as I know, Project LAMPLIGHT and the early ZEUS studies are the first that analyzed a complex system with functionally separate parts interacting.

Today, we are approaching the third stage with, I hope, due diffidence and caution. This stage is the analytical study of forces that have different kinds of weapons and different missions. The problem is to find optimum combinations of these disparate elements to achieve a specified result. If this kind of analysis can be done well. then the kind of force structure analysis that General Phillips spoke of yesterday can be done well.

There is one note of caution about this third stage that I must stress. The effectiveness of combined arms forces can never be predicted statistically because they depend on the enemy's reaction. If this is true. there is no such thing as a generally optimum proportion of tanks, infantry. and artillery because that optimum depends on the proportion and tactics used by the enemy. In game theoretic terms, the optimum mix is, itself, a mixed strategy for both sides. Since the US Army cannot change its overall mix very quickly, the existence of a feasible optimum is doubtful.

One reason for the reduction of sub-optimization has been the vertical diffusion of Operations Research in the Army. Beginning with the establishment of the OR Group in the Chemical Corps in 1952, there has been a rapid proliferation, most notable in the Ordnance Corps, until today nearly every organization dealing with R & D has some kind of agency that is at least called Operations Analysis in some form or other. This vertical diffusion makes it possible for the Army General Staff, the Assistant Vice Chief of Staff, and the DoD Systems Analysis people to build aggregated models with some degree of confidence that their feet are on the ground through the work of these other groups.

So much for sub-optimization.

Non-Quantitative Factors

Alongside of the reduction in sub-optimization, there has been a parallel development away from the purely quantitative to more qualitative OR studies dealing with the behavior of people and the interaction of military forces with American national policy. This trend has been particularly notable in the Army, perhaps, because of the attitude described by the old cliche: "The Army equips men; the other services man equipment."

Two examples can illustrate this point. As far as I know, the first non-hardware OR study that was of major importance, whose recommendations were adopted, and whose predictions were correct concerned the integration of Negro manpower in Korea. Should the Army insure that Negroes were proportionally represented in all units, or should they be in separate units? The study recommended integration across the board. The predicted impact was observed after the President ordered integration in July 1952.

The second example involves the impact of political and psychological effects on the effectiveness of weapons. The study examined the theoretical effectiveness of a particular weapons system in NATO Europe in purely military terms. The study compared this effectiveness with the use of the weapon in current NATO plans. These plans encompassed not only political constraints but implicitly took account of the psychological attitudes engendered by these constraints on the peacetime activities of the commanders concerned. The study then examined what increases in effectiveness would accrue if a certain R & D program were successful. The results showed that 32 percent of the effectiveness was thrown away because of the political

and psychological factors. The results also showed that a successful R & D program would provide only marginal changes in effectiveness as long as the political and psychological constraints remained. The study recommended certain actions to remove some of the constraints as a pre-requisite to a useful R & D program. This is the kind of interaction of political, technical, and operational factors that should be studied more if OR is to serve decision-makers at higher levels.

The Shifting Allegiance of OR

In World War II, OR studies were clearly operational in the sense that they were written for and used by operational commanders. The studies dealt with tactics as much as hardware. Changes could be put into effect very quickly. There was immediate feedback. The operations analyst knew very soon whether and by how much his predictions were correct. The results, however, were not valid for long. The enemy soon reacted to the new hardware or the new tactics and a further reaction was required by the analyst. Today, we tend to forget this tactical reaction by the enemy. So-called official intelligence estimates tend to become immutable inputs and the results of studies now may exaggerate the effectiveness of new weapons or tactics because enemy reaction is rarely considered.

After World War II, the emphasis in OR changed to R & D with particular attention to nuclear weapons. Costs appeared in terms of fissionable material, if not dollars.

Then came Korea. Air Force and Navy OR shifted again to operational problems facing the local commanders. The Army emphasis, however, was somewhat different. Psychological warfare, studies of the effectiveness of the

individual soldier in combat, command, control, and communications received more attention than more traditional studies of tanks, infantry, and close air support. More control of OR was maintained by the Pentagon Army over activities in the field than was the case in the Air Force or Navy.

After 1953, there was a major shift toward research and development. Almost all of the work, as far as I know, was directed at future systems: either doctrine and tactics, organization, or straight hardware elements or systems. This allegiance continues today.

In the late 1950s, there was another parallel development: the growing use by the Services and the Secretary of Defense of OR as a management tool for controlling the military establishment. In a sense such use of OR dealt with operations. But they were the peacetime operations of Pentagon managers. The tools were adaptations of industrial management techniques.

Summary

To summarize, I would like to view Operations Research/Systems Analysis as evolving along three parallel lines, the emphasis shifting in accordance with the personalities of the men in power. Systems Analysis has become identified with the allocation of resources to various missions by the Secretary of Defense. Its value to him is as a means for retaining control over a huge and complex organization. Operations Research is commonly identified with estimating which of the enormous number of technical choices available the R & D manager should choose. So we have OR as a supplement or complement to systems engineering studies, a tool to insure that we are not optimizing a system for which there is no need.

Operations Research in its original sense, I fear, has taken a back seat. There are few studies of operations for their own sake and as a basis for improved R & D. The Viet Nam data lack is obvious to us all. I would like to make a vigorous plea for more operations research studies on operations and to give an example that is not related to Viet Nam operations.

Several years ago there was a major test of the first two battalions of a new system that existed in the Army. It was a brand new system that had never been in the field before. Yet the test was not planned as part of the original program. In preparation for this test, we found 27 bookcase-feet of studies dealing with the effectiveness of the system before any battalions existed but no plans to find out whether the assumptions in these studies were correct, no plans to provide data on the utility of the system. It seemed to us a very good idea to send some people out with a stop-watch and a notebook to see what the actual numbers were.

The trouble, today, is that there are too few such tests to make certain that we keep our feet on the ground with measured data and make certain that we do not parrot the assumptions of ten years ago.

What we need is more Operations Research on the operations of military units in the field.

A CRITICAL LOOK AT WEAPONS SYSTEMS STUDIES

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A gathering such as that today of persons interested in operations analysis presents a welcome opportunity to offer a critique of our operations research and weapons systems studies. The purpose of this critique is not just to generate heat, but to light the way toward more useful studies, improved research and better papers. Some in the audience are practicing operations analysts. Some are the buyers and users of weapons systems studies. And some are all three. But no matter what our connection with operations research it behooves us to cast a critical eye at weapons systems studies. As practitioners we need to improve our work. As buyers or users we want to improve the product we get and to know how to judge its value.

As an analyst does a study he continually asks himself - and his colleagues - a whole series of questions. One of the most fruitful of these questions is: How can the study be improved, or what are the shortcomings of the analysis? Typically the answer is: "Give us more time, extend the deadline". This brings me to the 1st law of weapons systems analysis, or indeed of military operations research. Just as in Parkinson's law for economists and in Murphy's law for engineers, there is much bitter truth in the 1st law of operations research. It states: "The more important or difficult a study, the less time there is to do it". The operations analyst almost always is confronted with a deadline that comes too soon. In view of this resource constraint the analyst must give early considerations to a series of "Thou Shalt" and "Thou Shalt Nots", or commandments, or rules, which I shall state in the form of aphorisms. The user of weapons systems studies can use these aphorisms to judge the quality of the product.

Many of these prissy statements in this paper are cast in a negative way. The reasons for this are several. In the first place it is much easier to critique a study than to do a good weapons systems analysis. Secondly, the negative statements make the points sharper. Thirdly, by this way of stating them they are more likely to be remembered and applied in a study.

Recommendation $\neq$ Decision

The decision maker looks at the results of a study and recognizes that the recommendation is not the same thing as a decision - not simply that otherwise the decision maker would be out of a job, but because he must consider many other factors than those the operations analyst was able to study. Some of these factors may involve international political problems of allies and potential allies; some may involve economic conditions of the country or of a segment of the country; some may involve long term strategies. Often the weapons systems under study have to be evaluated with several measures of effectiveness, in recognition of the several missions they may perform, and these effective measures often can be integrated only subjectively, which is a task for the decision maker. For example, in strategic weapon systems like

bombers and ICBM's, there may be a counter-force mission and a retaliation mission. These cannot be combined in an objective way, for they reflect vastly different strategies.

Thus the reasons for a recommendation are at least as important as the recommendation, for if the reasons are given the decision maker can weigh all the factors in arriving at a decision. The decision maker may decide against the recommended weapons sytems, for the benefits to be gained from an alternative weapons system, when viewed from a higher vantage point, may outweigh the gains in effectiveness shown for the preferred system in the study.

Value of study $\not\propto$ Cost

Judging the value, or quality, of a study is not easy. In particular the value of a study is not proportional to the cost. Some people say, "You get what you pay for". But if this were really so, there would be no need to do a weapons systems analysis and certainly no need for a cost-effectiveness study. All the decision maker would have to do is pick that weapons system which comes closest to his budget limit. Among other things we, as analysts, would be out of a job. Hopefully, this paper will show more cogent reasons for not abolishing our job. In passing, let me mention that the security classification is also no indication of the value of a study. A top secret study is not *ipso facto* good. Nor is the number of analysts employed in the study an indication of the study's quality.

Model $\not\equiv$ Study

Most weapons systems analyses and most cost-effectiveness studies involve a model. An aphorism I want to bring to your attention is that a model, be it an elaborate operational game with two opposing teams and an umpire, or a detailed simulation on the largest computer, or an elegant analytical expression does not constitute a study. A weapons systems study involves far more than a model. While computers today are widely used, they are not always wisely used. Too often, unfortunately, a great deal of our study resources, in terms of time, manpower and money, are spent on developing a model for a computer without the necessary prerequisite thought of the relevance of the model to the problem, of the operational concept we are trying to modelize, and of how what the computer ingests is to be obtained, or how what it spits out is to be used. Without this prior thought - and it is hard work - a model is just a set of equations and logical statements with no, or perhaps little, relevance to the problem. A model is not reality and its application is not an experiment. A model reflects certain idealized parts of the real world. Careful thought should be given to the assumptions of the model - those that are explicitly stated and those that are implicit in the model.

Computations $\not\equiv$ Study

The applications of a model, the set of computations, do not constitute the evaluation of a weapons system. The tons or miles of paper produced by

the computer are useful only if their contents can be analyzed and if they are relevant to the problem under study. There is the question of the sensitivity of the results to the model parameters. And there is the question of the appropriateness of the effectiveness measure and of the cost-effectiveness measure the model is to evaluate.

Detail ≠ Quality

The fifth prissy statement says that a detailed model is not necessarily a good model. This statement may come as a shock to some people. The counter I have heard to this precautionary statement is that while perhaps detail is not always good, it doesn't do any harm either. But there are a number of ways in which detail can do harm. The audience that attends a briefing on the study may get distracted by detail and not see the forest for the trees. Further, to the extent that resources - the time, manpower and money - are squandered on unnecessary detail in a model, it would not only be harder and more time consuming to provide inputs for the model, but the examination of other facets of the problem will be sacrificed. The key here, of course, is the adjective "unnecessary". In the study of aircraft for air-to-air combat, for example, there is little sense, on the one hand, in modeling the detailed thrust variation of the engine, the roll rate, the angle of attack, and the response rate of the control system of the aircraft, or to integrate the equations of motion of the aircraft every 1000th of a second, and, on the other hand, to ignore the dynamic aspects of the duel. For the tactics employed by each aircraft, the decision as to what to do next, is the most important factor in determining the outcome of the air-to-air duel. A friend of mine cast this criticism as the next aphorism.

Approximately Right > Precisely Wrong

He says he would rather be approximately right than precisely wrong. Perhaps the judgment that is applied in deciding what detail is unnecessary is, in part, what makes operations research different from mathematics or from engineering. For it is a judgment that involves recognition of the whole weapons systems problem. I suggest that in our weapons systems studies we act more like operations analysts and less like mathematicians and engineers. Related to the question of detail is the seventh maxim.

Analyzable ⇏ Important

Just because a part of a weapon system can be analyzed, this does not mean that it is not important to the study. The question of importance, or relevance, should come first. I am reminded of the drunk I came across one night. He was searching the ground around a street light. I asked him what he was looking for, and he replied, that he had lost a nickel, the price of his next drink - (that was in the old days). When I asked him where he had lost it, he said further down the street in the dark. So I asked him that if he lost his money in the dark why was he searching around the street-lamp? He said he was searching around the lamp because that was where the light was! A study is no better than its weakest link. In working a problem we tend to do that which we know how to do, whereas we should devote research effort to finding and studying the hazy areas, the weak links.

Non-Quantitative $\not\Rightarrow$ Excluded

There are always quantitative factors in a problem. Sometimes a study ignores the non-quantifiable aspects. The morale of troops, their training level, the reaction of the enemy, the tactics of a combat unit, the location of a future war are not quantifiable. But this does not mean that they should be ignored in the study of weapons systems. There are always quantitative factors to which no numbers can be assigned in a meaningful manner, but which none the less must be studied. One example is the next caveat.

Uncertainty $\not\Rightarrow$ Probability

While probabilities may be thought of as dealing with uncertainties, there are uncertainties which cannot be cast in objective probability terms. For example, an enemy development of a particular bomber for ten years from now, or the development and employment by the enemy of a noise jammer as a penetration aid to counter a surface-to-air missile, or of a particular tank, or of a tactical missile, or the intentions of a potential enemy are not measurable quantities. To treat these uncertainties in a probabilistic manner is meaningless.

Future $\not\equiv$ Single Possibility

The tenth aphorism, while almost universally recognized as a truism is often ignored. The evaluation of a weapon system for the future does not involve an oracular pronouncement based on gazing into a clear crystal ball. A single point projection to the future, no matter how detailed, does not provide a sufficient basis for the evaluation of a weapon system. There are many possible environments, many possible employments, many tactics, many enemy reactions, and many uncertainties in a weapon systems performance characteristics. No one point estimate of the parameters and factors constitute the future.

Most Probable $\not\equiv$ Actual

In particular, the most probable situation is not the one that is actually going to obtain. The careful study of one particular application of a weapon system in one particular scenario involving the geography, environment, and tactics, with one particular type of enemy reaction may give us a good understanding and vivid portrayal of the situation, and as such may be quite instructive, but it is an insufficient basis to evaluate a weapons system. For example, if we think of a weapons system with a dozen parameters and we assume that each parameter has a chance of .75 of taking on one particular value of interest, then the chance that all 12 values will be what we think they will be is less than one in thirty. This is an obvious over-simplification. Parallel to this is another non-identity.

Average $\not\equiv$ Adequacy

The real world will not be that of averages. I am sure you have all heard about the statistician who could not swim and drowned in a lake that had an average depth of less than two feet. He had stepped into deep water.

In a weapons system study the analyst must consider many different conditions or situations including some extremes, because the enemy can be expected to search for and find weak links in our military posture. Varying the parameters, investigating the sensitivity of the model structure and of the effectiveness measures are absolutely essential to a proper weapons system evaluation. The problem of the effectiveness measure requires emphasis.

Effectiveness Measure = f(Problem)

This positive maxim tersely states that the effectiveness measure is a function of the problem. If the measure is selected improperly the study may be useless. In a study of armor plating a bomber to reduce its vulnerability to enemy fire, the measure of effectiveness should not be the reduction of the aircraft's attrition. If the only interest in armoring an aircraft were to reduce its attrition, the conclusion would be to leave the bomber home. Don't expose the aircraft to the enemy! A more proper measure of effectiveness would reflect the mission of the aircraft. It would thus reflect the enhanced probability of the aircraft to penetrate the defenses and to destroy the target. If too much weight were devoted to armor, the bomber would have a reduced payload to deliver to the target, and the target may not be destroyed. Similarly the measure of effectiveness of an AICBM should not be its ability to destroy an incoming reentry vehicle, but to minimize damage to the city, both from the enemy reentry vehicle and from the friendly AICBM.

Good (US) $\neq$ Bad (SU)

War is not a zero-sum game. It is not even necessarily a negative-sum game. For example, when two nations go to war each nation may expect to gain something by going to war. It regards the alternatives as less desirable. Therefore, at least at the beginning of the war both sides may view the gain as positive when compared to the alternatives. But more to the point, the opposing sides of the war don't necessarily have the same, or opposite goals in mind. This holds true for individual battles as well. For example, in Southeast Asia when the enemy attacks an airbase with mortar fire, we want to defend ourselves, mainly, I think, to minimize damage, so that the base remains operational and sorties can be launched. The enemy's objective may not be the opposite at all. His objective may be, for example, to set large fires which can be seen for miles and miles around and thus affect not only the morale of his own troops but affect the minds and hearts of the local citizens, or of those even thousands of miles away. In the Korean conflict both sides felt it to their advantage to recognize certain sanctuaries in which the opponent was safe.

Aphorisms

1. Recommendation $\neq$ Decision
2. Value of Study $\not\propto$ Cost
3. Model $\neq$ Study
4. Computations $\neq$ Study
5. Detail $\neq$ Quality
6. Approximately Right - Precisely Wrong
7. Analyzable $\neq$ Important

8. Non-Quantitative $\nRightarrow$ Excluded
9. Uncertainty $\nRightarrow$ Probability
10. Future $\neq$ Single Possibility
11. Most Probable $\neq$ Actual
12. Average $\neq$ Adequacy
13. Effectiveness Measure = f(Problem)
14. Good (US) $\neq$ Bad (SU)

There are many more prissy statements, or aphorisms, which can be given. Such terse statements are useful, I believe, not only in critiquing a study when it is completed, but, more constructively, in developing improved studies. In view of the finite resources available to weapons systems analysts, compromise in the approach to the study is necessary. Balanced application of the aphorisms would serve as a useful guide.

Finally, I would like to make two suggestions that I believe would make for better weapons systems evaluations.

Suggestions

1. Several Models and Effectiveness Measures
2. Study Half-Life

The first suggestion is that a study should employ more than one model. There should be several parallel models with different viewpoints and different assumptions. And there should be more than one measure of effectiveness in evaluating weapons systems. This first suggestion is directed at covering a broader spectrum of employment possibilities of weapons, and is made in view of the fact that any model represents a limited view of the possible applications of weapons. The second suggestion is a management tool that has been found immensely useful in weapons systems studies. When starting a study, management should set a target date approximately half-way to the deadline. A good first cut of the study should be completed in that time, followed by a review of the approach and of the quality of the study. The feedback resulting from this review is tremendously beneficial in completing the study. Management and the analysts should use the aphorisms as a guide and then take those actions necessary to improve the study.

THE EFFICACY OF ANALYTICAL MODELING
IN WEAPON SYSTEMS ANALYSIS

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The University of Michigan

Introduction

The necessity for quantitative approaches to weapon system and force planning, and the contribution of cost effectiveness analyses, is well recognized and need not be expounded upon here. As the name implies, cost effectiveness analyses require not only the generation of cost information, but also a means of measuring or predicting the combat effectiveness of weapon systems and force structures. My presentation today is concerned with the latter problem--methods to assess and analyze the combat effectiveness of weapon systems and mixes of weapon systems.

It is important to understand the differences implied in my choice of the terms "assess" and "analyze" combat effectiveness. By a combat effectiveness assessment of weapons systems, I am referring to the determination of an effectiveness number for each of a number of candidate systems to ascertain which is more effective. A reasonable synonym would be evaluation. By a combat effectiveness analysis, I am referring to the activity which determines the contribution various factors have on combat effectiveness. More explicitly stated, it is an activity which determines the marginal effect of changes in weapon capabilities, weapon mixes, tactics, threat, and other relevant aspects of combat--information requisite to the synthesis of cost-effective combat systems.

Approaches to Modeling Combat Effectiveness

Many quantitative methods have been used throughout the history of military operations research to determine the effectiveness of combat organizations and equipment. A few of these are shown in Figure 1.

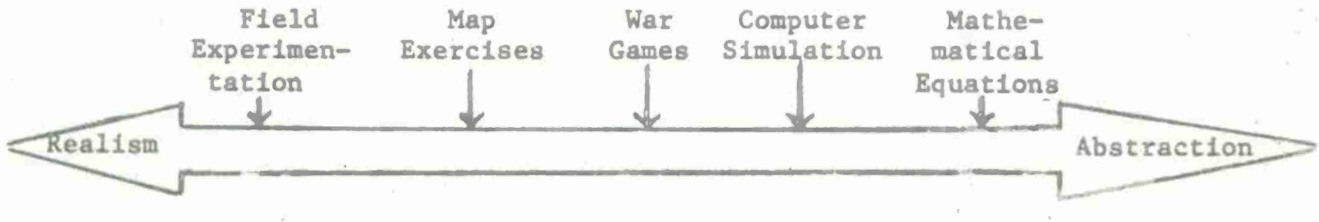

Figure 1. Spectrum of Methods for Combat Effectiveness Studies

This figure depicts a continuum bounded at one end using exclusively analytic mathematical descriptions and on the other by experimenting with existing military systems.

In addition to the progressive loss of realism as we move along this continuum from field experimentation to mathematical equations, a number of other factors vary which are relevant to selection of a methodology for use in a particular study:

1. The number of participants decreases. Computer simulation and mathematical equations employ no active participants.

2. Associated with the smaller number of participants is the loss in freedom for decision making within the methodology. This reduces subjectivity and the output variance due to the selection process for the participants.

3. There is a decrease in cost of both developing and utilizing the methodology.

4. The models become more manipulatable as we move towards more abstraction in that there are fewer numbers of variables considered, and

5. The models, if valid, provide more generalization. This is most observable at the mathematical equation end of the spectrum, where the equations may provide general theories of particular processes.

Weapon system planning studies have most usually employed either Monte Carlo computer simulation or analytic mathematical formulations to estimate combat effectiveness. This, I believe, is due primarily to the fact that neither of these methods employ explicit participants or decision makers as active elements. This, as noted above, reduces the output variablity which more readily facilitates assessment and analysis of proposed weapon systems. Examination of both of these approaches (Monte Carlo simulation and analytic modeling) indicates some obvious advantages and disadvantages as methods for weapon system assessment and weapon system analysis.

As is well known, the Monte Carlo simulation approach is a means of modeling the combat situation in minute detail explicitly including candidate weapon system capabilities; threat variables such as their numbers, types, and capabilities; and the interactions among candidate and threat characteristics, the environment (terrain, weather, etc.), and tactics employed. The actions of each and every weapon system in a combat unit can be recorded during the course of a battle and eventually analyzed. Although the Monte Carlo simulation approach is a powerful evaluation tool, there are a number of technical and related financial problems associated with the use of this technique on a complicated process, such as combat engagements. An initial practical drawback to Monte Carlo simulation is the cost and time requirements to construct a reasonably realistic descrip-

tion of the process. It would not be unreasonable to spend three to four man years in just developing a Monte Carlo simulation of combat engagements such as Carmonette (Adams, 1961) or the Ohio State University's DYNTACS (Howland & Clark, 1966). An additional financial constraint exists when employing a Monte Carlo simulation approach. If the process is described in the requisite detail, each replication of the process could reasonably require five to ten minutes of computer time[1]. Multiplying this by the required number of replications to obtain statistically sound results gives rise to sufficiently high costs to operate the simulation. Particularly important to an analysis study is the fact that, when microscopic detail is incorporated in the simulation, it is in practice very difficult to single out the independent variables which have significantly affected the combat results. Evidence of this phenomena is seen in the Carmonette tank warfare simulation where, after many years of experience with it, it was still difficult to single out the independent factors which most contributed to the effectiveness of tank systems.

An alternative approach to the modeling of combat operations for weapon system planning is the classical one of analytical modeling. In this approach, the physical situation is studied and mathematical descriptions of the process are hypothesized. The advantages of analytic approaches are straightforward. The expenditure of time and financial resources for development and utilization of the model are markedly reduced. More importantly, the relationship between independent factors of the process and the process output is usually explicitly presented. The major problem with employing this approach is that much of the process detail must be ignored to simplify the mathematics. Additionally, many of the random variables of the process that are considered in digital simulation must be suppressed and expected values used rather than employing their total distribution.

The choice of which approach to use in any particular situation is, of course, dependent upon available resources (financial and technical) and the specific study objectives. Although it would appear that analytical modeling is a more robust tool for weapon systems analysis (due to the explicit relation between input and output), and is more efficient than simulation in performing requisite sensitivity analyses in weapon system assessments (evaluations), digital simulation is the predominant, if not exclusive, approach used in weapon system studies. This state of affairs is, I believe, based on the prevailing attitude that the increased realism of detailed simulations will produce more "realistic" results. To test this hypothesis, an analytic model of mechanized infantry operations was developed for comparison of combat effectiveness results generated by Cornell Aeronautical Laboratory's simulation of the same

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[1]Test runs with the Carmonette simulation required two minutes of computer time to simulate one minute of battle in a single replication (Adams, 1961, p. 35).

operations[2]. The combat situation and comparative results are described in the following section.

Combat Situation and Comparative Results

The combat situation modeled in the Cornell simulation and the analytic formulation is shown in Figure 2. It depicts an infantry heavy mechanized battalion task force attacking a defended enemy position across 3000 meters of terrain. The strength and composition of the attacking and defending forces are given in Table I.

Table I - Force Strength and Composition

Red	Blue
2 - Rifle Platoons	16 - Armored Personnel Carriers
6 - BTR-50 Personnel Carriers	10 - Main Battle Tanks
2 - T-62 Tanks	
6 - Anti-Tank Rocket Launchers (ATRL)	
2 - 85 mm Aux. Propelled A.T. Guns (APAT)	
1 - Swatter A.T. Guided Missile (ATGM)	

The BTR-50 had a 23 mm cupola-mounted weapon as its main armament and the T-62 had a weapon comparable to the U.S. Shillelagh.

The scenario described by the Monte Carlo simulation contained a number of operational tactics and rules of engagement such as (a) main battle tanks attack 300 meters in advance of the personnel carriers, (b) open fire ranges, (c) firing restrictions, and (d) firing priorities. The same operational tactics and rules of engagement were incorporated in the analytical model with the exception that the main battle tanks and personnel carriers attacked in line. Additionally, the location of the defensive line on the battlefield in the analytical model was taken to be the horizontal centroid of the deployment area used in the simulation model.

Comparative results of an evaluation of a specific armored personnel carrier are shown in Figure 3. The figure depicts the (force) ratio of surviving blue infantry still attacking the objective to the number of surviving red infantry at the objective. This measure of effectiveness

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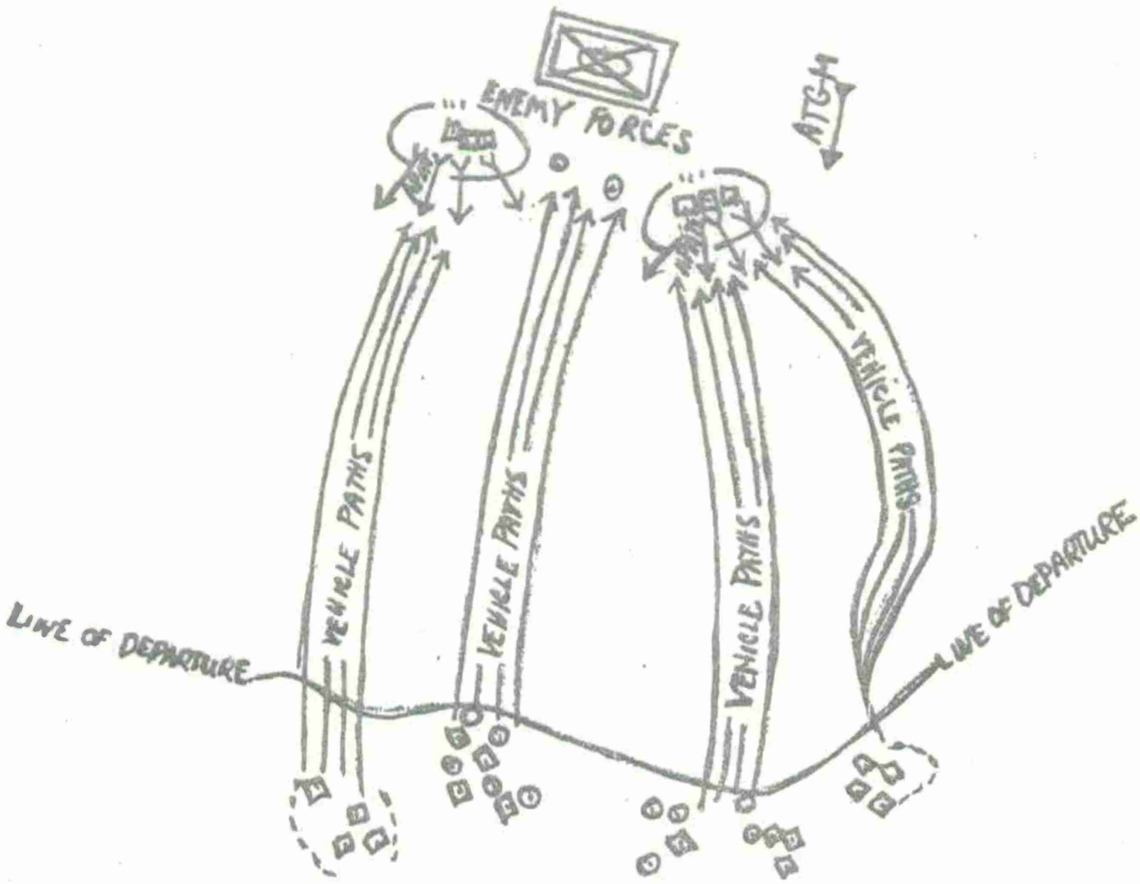
[2] Favorable comparison of an analytical combat model with a digital simulation one should not be interpreted as experimental verification of either. Both models may describe the same dynamics but may be poor predictors of the outcome of real world combat actions.



Armored Personnel Carrier

Tank

0 .2 .4 .6 .8 1

Scale = Kilometers

Antitank Rocket Launcher

85 mm APAT

ATGM

Figure 2

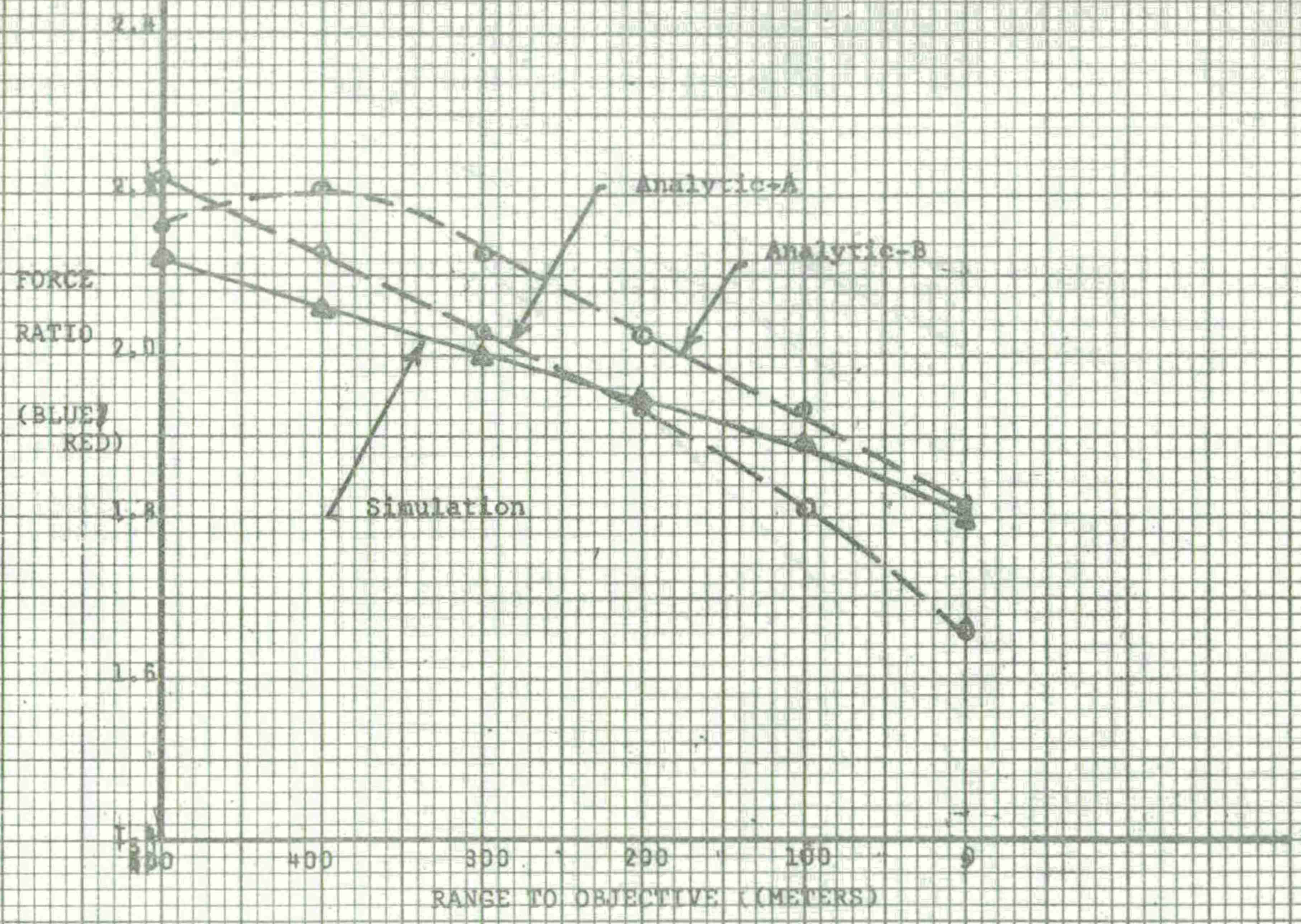


Figure 3 - Surviving Force Ratio

is used in the Cornell study under the assumption that the ratio at the objective is an indication of the probability of seizing the objective. Two force ratio trajectories are shown for the analytical model since it was not possible to determine the relative position of all weapon systems in the Cornell simulation when they reported their range "zero" results[3]. The two trajectories represent reasonable interpretations of the meaning of range "zero". The figure indicates that the force ratio trajectory of the simulation and analytical models are reasonably similar. The final force ratio of Analytic-B is essentially identical to the simulation result.

The sensitivity of a ratio measure to absolute magnitudes of surviving forces and the expanded scale used in Figure 3 produce a misleading impression that the simulation and analytic models are only moderately correlated. The absolute numbers of surviving forces at the objective given in Table II suggest a much stronger similarity between the two approaches, especially with Analytic-B

Table II - Surviving Forces at the Objective

	Simulation	Analytic-A	Analytic-B
Blue MBT	7	7	7.4
" APC	13	10.7	12.1
" Infantry	122	107	121
Red Tanks (T-62)	0	0	0
" APC (BTR-50)	4	4.5	5.0
" ATRL	3	1.7	3.1
" APAT	1	0	0
" Infantry	68	64.7	67.1

Figure 3 And Table II suggest the similarity of the simulation and analytic models for evaluating the effectiveness of specific armored personnel carriers (weapon system assessment). Their correspondence as tools for weapon system analysis purposes is illustrated in Figure 4 which shows the effect of varying the attack speed on the surviving force ratio. The figure suggests that increasing the attack speed is beneficial in that it increases the final force ratio; however, the marginal increase in final force ratio decreases for each unit increase in speed. Thus

[3]This is due to the fact that the simulation model considered spacially distributed forces and the main battle tanks attacking 300 meters in advance of the armored personnel carriers.

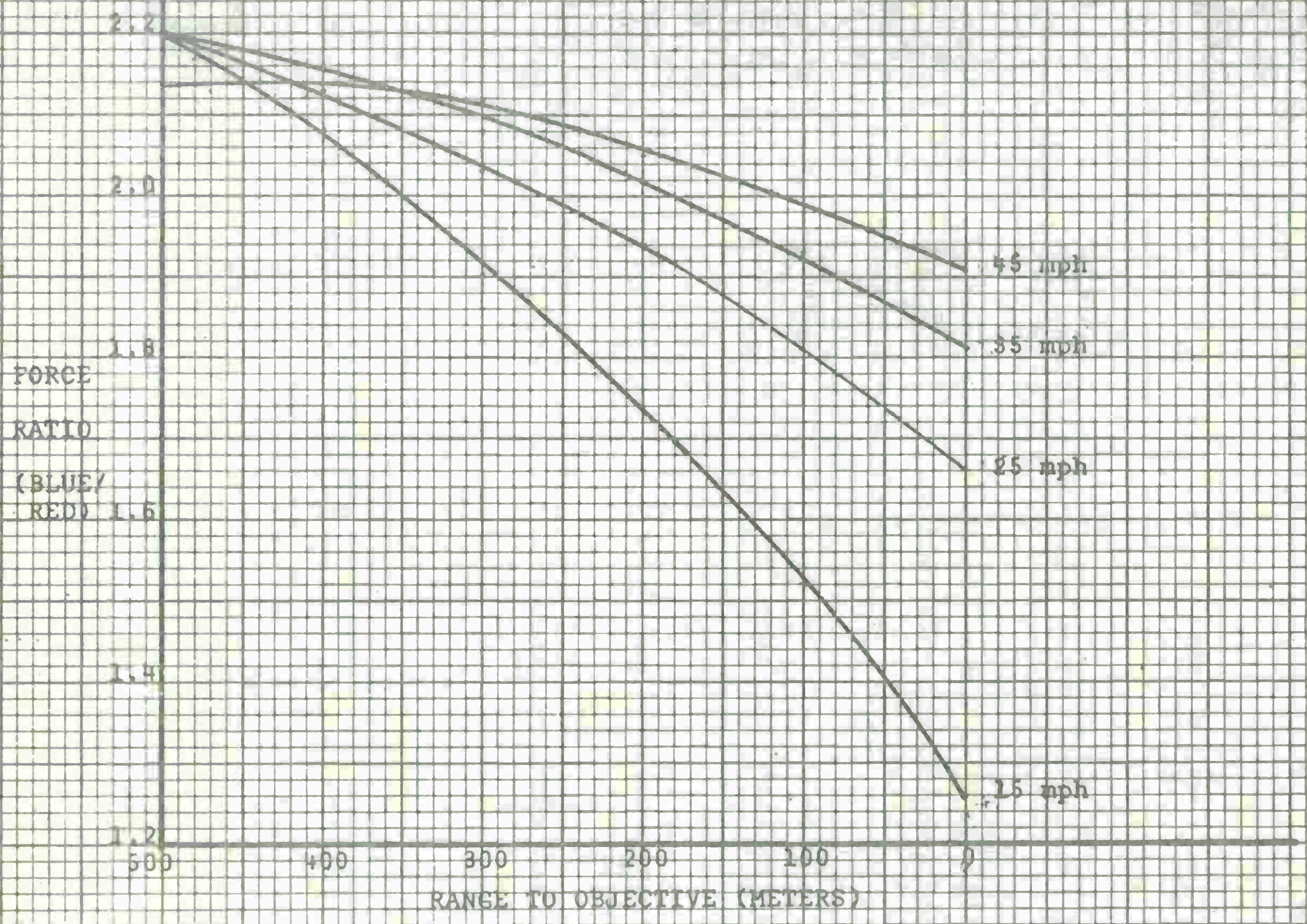


Figure 4 - Effect of Attack Speed - Analytical Model

one might be willing to pay (in a monetary sense) for an increase in attack speed capability for a conceptual APC from 15 mph to 25 mph, but further increases to 35 mph and 45 mph offer progressively smaller returns in effectiveness. These results are identical to those arrived at in the Cornell study. A more general form of this decreasing marginal return of attack speed was previously developed by this author (Bonder, 1965).

Conclusions

The above example suggests that abstract analytic models may produce quite similar combat effectiveness results to detailed Monte Carlo simulations. When this obtains, it appears reasonable to use the former as a supplement, and possibly a substitute, for the latter. Unfortunately, no general *a priori* conditions are known which ensure this isomorphic relationship. Accordingly, both the simulation and analytic models need to be constructed[4] and their correspondence tested before the analytic model can be advantageously used. This correspondence is facilitated by using the simulation results to estimate parameters of the analytic model rather than developing the latter as a separate entity. Once correspondence is established, the analytic model can be used for the following purposes:

(a) Sensitivity analysis to determine the effect of errors in input data.

(b) Evaluation of candidate weapon systems that are variations of systems already evaluated in the simulation model, i.e., use the analytic model as an interpolation mechanism.

(c) Under the reasonable premise that each candidate weapon system should be evaluated under operating conditions (attack speed, open fire ranges, etc.) that are approximately optimal with respect to its performance capabilities, the analytic model can be used to determine efficiently these conditions for each system prior to evaluation in the simulation.

(d) Parametric variation of weapon system design characteristics, tactics , and organization structures to determine areas of high marginal payoff in combat effectiveness, i.e., weapon system analysis.

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[4]Development of an analytical model is usually a negligible expenditure of resources relative to the simulation model. Development of the analytical model in the above example required approximately one man-month of effort.

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OPERATIONS RESEARCH EDUCATION FOR THE MILITARY

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Educational programs for military officers have expanded greatly since the early days of applying operations research to military problems in World War II. There have been several significant events since World War II that stimulated educational programs in operations research for military officers. One of these was the Korean war, another was the appointment in 1961 of Mc. McNamara when he established a planning-programming-budgeting system for the Department of Defense. The Army, Navy, Air Force and Marine Corps have all increased the number of specialty positions that require training in operations research and also the number of officers entering operations research programs. The service academies at Annapolis, West Point and Colorado Springs have initiated operations research courses, or have minors in operations research, at the Bachelor of Science level. The services are sending officers for graduate education in operations research to the Naval Postgraduate School, the Air Force Institute of Technology, and various civilian universities.

Our panel today is composed of four officers: One from the Marine Corps, one from the Army, one from the Navy, and one from the Air Force. Each of these officers are involved in training and setting requirements for education in military operations research. Each speaker will summarize the requirements of operations research-trained graduates in their respective service and will discuss the various educational programs that the officers are being sent to, and also how these programs meet the requirements. We should have sufficient time for an extended discussion period at the end of the forum.

U. S. ARMY TRAINING IN OR/SA

LTC Raymond P. Singer
OACSFOR, DA

SLIDE 1 ON

As OR/SA became ingrained in the Defense Establishment decision process it became apparent, even to the Army, that trained military personnel were essential to efficient functioning of the system.

We were expending in excess of $50 million a year on studies and analysis, and if anything positive could be said about the products of the system it was that they were never acceptable to the Army and to OSD simultaneously. We were dissatisfied with many of our studies but we really didn't know why.

It therefore became apparent that we had to have military personnel who were professionally trained, who could monitor what was going on and who could conduct an intelligent conversation with OSD.

SLIDE 1 OFF

For the following reasons it was decided to establish an Officer Special Career Program in Operations Research/Systems Analysis.

1. Essentiality of OR/SA in the Military Decision Process
2. Scope of the OR/SA effort
3. Dissatisfaction with past study results

SLIDE 2 ON

Officer Special Career Programs are established when there are requirements for special skills which require extensive training and should be used on a repetitive basis, but are not branch oriented. An example of such a requirement is Army Aviation. Pilots are required and their talents should be reused. No specific branch has a corner on the requirements. The problem could not be solved by giving pilot training to all officers of any specific branch.

OR/SA is the newest of the 12 special career program. All programs are operated by the Office of Personnel Operations and monitored by a specific DA staff element. The Assistant Chief of Staff for Force Development monitors the Atomic Energy and OR/SA Officer Programs.

SLIDE 2 OFF

In the OR/SA Special Career Program we deal with two types of individuals, OR/SA Specialists and OR/SA Executives. The definitions of the two types of personnel are shown on this chart.

SLIDE 3 ON

As you can see from the definitions the OR/SA Specialist is a formally trained professional in the field. He is a doer or a team chief.

The OR/SA Executive is an individual who has received a special orientation to better fit him to perform his executive duties in study management.

The note at the bottom of the chart was intended to clarify the two terms, but merely added to the confusion. Despite the normal day-to-day understanding of the terms "specialist" and "executive" they are not intended to connote progressions in a career pattern. A man in the program does not go from unrated, to specialist, to executive. Once a man is "knighted" as a specialist he can never become an executive. He is always carried on the books as a specialist since the prerequisites to be a specialist are more stringent than those to be an executive. There will be times when specialists are assigned to executive positions, but is recognized that, in essence, they will be overtrained for the job.

SLIDE 3 OFF

One of the responsibilities of the DA staff monitor for a special career program is the determination of the personnel requirements for the program.

In this respect, OACSFOR canvassed the Army world-wide to determine those positions which required OR/SA specialists and executives. This chart shows a summary of the processed replies from the field.

SLIDE 4 ON

The overall requirement is for 871 personnel, 384 specialists and 487 executives. For both types of personnel the distribution is approximately 10% in OSD and on the Joint Staff, 40% in HQ DA, and 50% in the major commands in the field.

A list of these positions is being published as Section V to AR 614-139, the Army Regulation on the OR/SA Officer Program. This list will provide the basis for requisitions to fill the key OR/SA positions.

SLIDE 4 OFF

A more detailed breakdown of the OR/SA positions is shown on this chart.

SLIDE 5 ON

I would like to emphasize that this represents our first try at determining OR/SA personnel requirements. The position list will undoubtedly be changed to a certain extent when the concerned agencies see the entire list in printed form and gain an understanding of the scope of the program. I would expect to see significant increases in the Deputy Chief of Staff for Logistics, Chief of Engineers and United States Army, Europe requirements. I can't help but feel that they did not get the message the first time around.

The cold hard fact of the matter is that if your position is not on the list, you will not get it filled by a trained man.

SLIDE 5 OFF

We have a requirement for 384 OR/SA Officer Specialists. How do we train them?

SLIDE 6 ON

We produce OR/SA specialists by sending selected officers to graduate school training at the Naval Postgraduate School, one of 17 universities, or to formal or on the job training at the Research Analysis Corporation, Stanford Research Institute, or the Institute for Defense Analyses. Next year the IDA program will be transferred to the Center for Naval Analysis.

The production of OR/SA specialists is a long arduous process. The validated requirement is for 384. Our assets were 19 at the end of 1965, 46 at the end of 1966, 93 at the end of 1967, and will be 137 at the end of this year.

Since specialists should spend alternate tours in OR/SA and in branch assignments and schools, we should have at least 768 specialists, or twice the requirement. At the current levels of production it will take us 10 years to reach that point, assuming no losses in the program.

While we are producing only a small percentage of our total requirement each year-about 60 a year, I would like to emphasize that training in this field has priority in our civil schools program second only to the training of Military Academy instructors. Our big problem, of course, is money. School funds, like all funds, are in very short supply. We worry a great deal about the $2000 per year that we spend on tuition and and not enough about the $15,000 we pay a student per year and the $50 million annual investment in the study program.

SLIDE 6 OFF

We are in better shape, and getting better faster, in the OR/SA executive area of the problem. Our requirement is for 487 executives. By the summer of 1970 we will have reached an asset level equal to 250% of the requirement.

SLIDE 7 ON

One of the formal schools used to train OR/SA executives is the OR/SA Executive Course at the U. S. Army Management School. It opened in January of this year and has a programmed output of about 550 students per year, Major and above and GS-13 and above. The OR/SA Executive Course is a 4½ week course. Some Army students attend a similar executive orientation course at the Naval Postgraduate School. The Army Research Office runs an annual 1 week course that really doesn't meet the requirement for executive training, but has been very well received. The Army Materiel Command sponsored a Mathematica-conducted Senior Officer orientation course at Princeton, New Jersey. Consideration is being given to continuing the course as an in-house, AMC activity at Fort Lee, Virginia. At the current time the Comptroller of the Army is considering the establishment of a study management course at Fort Belvoir this summer, or fall.

These then are our sources for formal orientation of OR/SA Executives. Short OR/SA courses are beginning to spring up like mushrooms. It is probably time to conduct a review of the objectives and circular of the several schools with a view toward some consolidation.

In addition to special orientation courses for OR/SA executives sub-courses in OR/SA have been, or are being, introduced into the Army branch schools, the Command and General Staff College and the Army and joint War Colleges. The sub-courses, some of which are required and some of which are elective, have been well received and are another reason for review and possible consolidation of our OR/SA Executive Training Program.

SLIDE 7 OFF

This then is where the Army stands as far as training in OR/SA is concerned. We have established an OR/SA Officer Special Career Program. The personnel requirements for the program have been determined and the training of personnel is being activity pursued.

We need to refine our requirements and adjust our training programs. Our critical problem is the shortage of OR/SA Specialists. Until the shortage of specialists can be alleviated, and this will take time, all we can say to our harried OR/SA specialists is that, like Avis, they will just have to try a little harder.

OPERATIONS RESEARCH EDUCATION FOR THE NAVY

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The Navy is vitally interested in operations research education for its officers. Since the early 1950's, the Navy has exerted considerable effort towards providing its own "in-house" analysis capability with Naval officers educated in this discipline. The culmination of this effort was the creation in August 1966 of the Systems Analysis Division of the Office of the Chief of Naval Operations (Op 96), largely staffed by officers with graduate education in operations research.

The Navy's major programs for providing operations research trained officers can be briefly summarized as follows:

(1) The two-year Master's level Operations Research/Systems Analysis Curriculum at the Naval Postgraduate School. Quota: 121 officers per year.

(2) The fourteen-month Master's level Defense Systems Analysis course conducted by the Institute for Defense Analysis. Navy quota: 10 per year.

(3) Doctoral study program. A small number of outstanding officers (about 5 or less) each year are approved for two or more years of Ph.D. study in operations research or related fields, either as a continuation of the Postgraduate School's OR/SA Master's program or as a direct input from the fleet having previously attained an appropriate MS degree.

(4) Undergraduate level. The U. S. Naval Academy now offers a two semester course in operations research for all midshipmen, plus a full majors and minors program in OR for those midshipmen who elect them. Starting in July 1968, five outstanding graduates from the OR majors program will be enrolled directed into the Naval Postgraduate School upon commissioning, for a special one-year Master's program in OR.

Because more than 90% of the Navy's current inventory of graduate educated officers in operations research are products of the Postgraduate School's OR/SA curriculum, the remainder of this paper will be devoted to a discussion of the development and current status of that program. The Defense Systems Analysis course will be discussed in other papers.

The Navy has long been in the fore-front of military operations research development. Shortly after U. S. entry into World War II both the Navy and the Army Air Force began work in this new field. Following a request from the Commanding Officer, Atlantic Fleet Antisubmarine Warfare Unit in April, 1942, the Navy's first O.R. group of seven scientists was formed on 1 May 1942. This unit's initial task was to analyze the results of sea and air attacks against German U-boats and to study means for improving efficiency of the forces employed in these operations.

This small, early group of civilians became known in 1943 as the Operations Research Group, and grew to a total of 73 scientists by the end of the war. These civilian scientists represented a diversity of academic disciplines, and they functioned as a single coherent unit attached to the Navy's top operational command in Washington. However, at any given time about one-third to one-fourth of these men were on rotation in the field, attached to Theatre or Fleet Commanders. This group has had a continuous history since its establishment, and is now called the Operations Evaluation Group.

Despite this "ground floor" experience in military operations research during World War II, there was little effort made immediately after the war to educate or utilize naval officers in analyst billets. In May of 1950, however, the Chief of Naval Operations recommended the establishment of an Operations Analysis Curriculum to satisfy what was then felt to be an urgent need for officers with fleet operating experience who also had the capability of scientific analysis and evaluation. In answer to CNO's request, the Chief of Naval Personnel in September 1950 approved the establishment of a "one year postgraduate course in Operations Analysis," and directed the Superintendent of the Naval Postgraduate School to implement this course at a suitable civilian institution, to accommodate an input of five officers per year. MIT was suggested as a possible site for this course.

Unsuccessful in his attempts to obtain an appropriate course at civilian universities, the Superintendent submitted a joint proposal with the Director, Operations Evaluation Group recommending the establishment of a six-term OA Curriculum at the Naval Postgraduate School. This proposal included a five-week intersessional working assignment plus a six-month terminal assignment. The Chief of Naval Personnel subsequently approved this proposal, but with the reservation that it might prove too difficult for the average Line Officer who had not specialized in higher mathematics at the undergraduate level.

The first class of nine officers embarked upon this new curriculum in August, 1951. It is interesting to note that our curriculum was implemented about a year prior to the establishment of the Operations Research Society of America. In May of 1952, the same Dr. Phillip M. MORSE, who has headed the Navy's first Operations Research Group, was installed as ORSA's first president. Publication of the first issue of the ORSA Journal followed in November, 1952. I should also mention that the second president of the Society was Dr. Robert F. Rinehart, now our Academic Dean at the Naval Postgraduate School.

This first class of the Navy's new Operations Analysis Curriculum was graduated in January 1953. Based on the experience with this first group, the Superintendent submitted a revised eight-term curriculum leading to a Master of Science degree, which retained the intersessional experience tour but eliminated the terminal work period. Particular improvements in the program resulting from the two academic term increases were: (1) inclusion of thesis work, with its accompanying research experience, (2) greater coverage in the significant areas of Operations Analysis, and (3) the inclusion of work on digital computers.

The Chief of Naval Personnel, with the concurrence of Chief of Naval Operations, approved the revised eight-term curriculum in July 1953, and it was implemented with the second class, numbering 15 officers. From that time the size of the annual input has varied from a low of four in 1957 to a high of 119 officers (includes all services inputs) during the present academic year, 1967-68. On

The imcompatibility between the rank/grade distribution of the P-Coded billet structure and the current inventory of qualified people is a further complicating factor. Due to this incompatibility, a total 100% utilization of the current inventory in OA P-coded billets can never be achieved. Therefore, the magnitude of the resources vs. requirements gap is effectively greater than the 340 officers mentioned previously.

Because of this gap, the Operations Research/Systems Analysis program has been assigned the largest annual quota (121 officers per year) of any single program in the Navy's postgraduate education system. The OR/SA Curriculum continues to be given top priority by the Navy's officer personnel and education planners.

The stated objective of our Operations Research/Systems Analysis Curriculum is "to provide selected officers with a sound education in quantitative methods and to develop their analytical ability in order that they may (1) formulate new concepts and apply the results of operations research/systems analysis with greater effectiveness, and (2) define and solve military problems more effectively."

The academic qualifications for admission are a baccalaureate degree with above average grades in mathematics, and completion of mathematics through differential and integral calculus. Navy line officers are additionally required to have had a one-year course in college physics.

The Operations Research/Aystems Analysis program is interdisciplinary in nature, consisting of course work in operations analysis, probability and statistics, mathematics, physics, economics and computer science. All students take a common core curriculum, with one exception, during the first year (four quarters) of study. The single variation is that the Navy line officers take a physics sequence-- one course in each of the second through the fourth quarters -- while all other officers take courses more appropriate to their particular career needs. For example, the Army officers take a sequence composed of Human Factors and Systems Design, Data Processing Management and Methods for Combat Development Experimentation.

Those officers selected for the Master's program continue for a second year of study, for a total of eight quarters overall. Students in the Master's program must complete a sequence of three elective courses approved by the Department of Operations Analysis, and they must submit an acceptable thesis on a topic previously approved by the Department. These officers are afforded the opportunity to qualify for the degree Master of Science in Operations Research upon their graduation. The elective courses include OR problems in Special Warfare; Theory of Systems Analysis; Econometrics; Advanced War Gaming; System Reliability and Life Testing; Applied Statistics and Decision Theory. The thesis topics normally are picked from an applied warfare area. Some typical recent thesis topics done by Army officers include: Parameter Estimates for Mathematical Models of Convoy Ambushes; An Inquiry into Machine Gun Automatic Rifle Trade-Off; A Media Allocation Model for Phychological Operation; A First Generation Simulator of the Thailand Transportation System; A Proposed Methodology for Determining Operational Hit Probability for M-60 Tanks.

1 July 1967, the official name of the program was changed from "Operations Analysis" to the longer title "Operationa Research/Systems Analysis."

Originally, the Operations Research/Systems Analysis Curriculum was designed for just Navy line officers - the "Operators," if you will -- but over the years, as OR techniques and methodology have extended into nearly all aspects of the industrial and civilian worlds, so too has the Navy extended its OR education to staff corps and restricted line officers. There are now supply corps, medical service corps, and communications security specialists among the Naval Officers enrolled in our program because in recent years analyst billets have been created for them throughout the naval establishment.

Let me digress for a moment at this point to discuss the Navy's subspecialty billet requirements underlying its postgraduate education program.

The Navy's subspecialty concept is an integral part of officer career development and was adopted to increase the depth of knowledge of unrestricted line officers in specific fields and to better utilize the abilities of these officers in meeting the needs of the Navy. A "Sub-specialty" is defined as a particular field of naval endeavor other than naval warfare, or a significant qualification in one of these fields obtained through a combination of formal education, functional training, and practical experience. Broad areas of naval warfare and qualifications such as aviation or submarines are not considered subspecialities but are considered part of the unrestricted line officers specialty of naval warfare and command at sea. A subspecialty, therefore, can be further described as a secondary career development field.

The "operations analysis" subspecialty is the one we are concerned with, of course, in connection with our OR/SA curriculum. At present the Navy has identified requirements for 290 operations analysis subspecialists, broken down as follows: 240 so-called "P-Coded billets," requiring incumbents with postgraduate level education; and 59 "S-Coded billets" requiring only baccalaureate level education. In the present inventory of officers who have had the requisite postgraduate education, there are about 260 OA P-Coded subspecialists. It would appear that the Navy has no problem then -- with 260 officers to fill 240 P-Coded billets. In order to provide normal rotation for these officers through "career rounding" billets to protect their "Promotability," it is necessary to have more than two qualified officers (depending on the grade/billet distribution) for each specified billet. The Bureau of Naval Personnel uses a factor of 2.5 as the multiple for the number of billets, in order to determine the sufficient number of qualified officers to fill the system. Under current policies then, the Navy requires an inventory of 240 x 2.5 = 600 operations research postgraduate educated officers. Thus, with an inventory of only 260, we have a current deficit of about 340 graduate trained OA subspecialists.

The Navy's 240 P-Coded operations analysis billets are roughly distributed as follows: (1) 50% are in Washington, D. C. in the office of the Chief of Naval Operations (OPNAV), Department of Defense, or other naval activities, (2) about 29% are on major fleet staffs, or other staffs which are part of the operating forces, and (3) the remaining 21% are on shore commands exclusive of Washington, D. C.

One of the exceptional features of the Master's program is the six-week intersessional practical experience tour taken during the second half of the fifth quarter. The officer students are assigned, on a temporary additional duty basis, as working members of appropriate military or industrial groups engaged in operations research on military problems. This field trip is intended to permit the student to actively participate in an operations research effort in the "real world." Secondarily, the experience tour is designed to assist him in finding a problem of interest for subsequent thesis study. Places where Army officers have spent their six-week experience tour include: Fort, Ord, California working on Combat Development Experimentation problems; at the Pentagon working on Systems Analysis problems, or at CDC Headquarters.

Those officers not selected for the Master's program at the end of the first four quarters remain in the Bachelor's program and complete one additional quarter's work (for a total of five quarters overall). Upon successful completion, these officers are awarded the degree Bachelor of Science in Operations Research.

All Naval officers who successfully complete either the Master's or the Bachelor's program are considered qualified to fill the Navy's operations analysis P-Coded subspecialist billets. Master's degree attainment is not necessarily a prerequisite for such a billet.

The present enrollment of the OR/SA curriculum is 183 students, distributed by service as follows:

United States Navy	-	87	
United States Army	-	58	
United States Marine Corps	-	35	
United States Coast Guard	-	2	
Foreign	-	1	(Turkish Navy)

The forecast for the future of the Naval Postgraduate School's Operations Research/Systems Analysis Curriculum is continued growth, as the Navy endeavors to narrow the gap between its operations analysis subspecialist resources and requirements.

U.S. ARMY TRAINING

IN

OPERATIONS RESEARCH/

SYSTEMS ANALYSIS

ARMY OFFICER SPECIAL CAREER PROGRAMS

ARMY AVIATION

ATOMIC ENERGY

AUTOMATIC DATA PROCESSING

CIVIL AFFAIRS

COMPTROLLER

FOREIGN AREA SPECIALISTS

INFORMATION

INTELLIGENCE

LOGISTICS

OPERATIONS RESEARCH/SYSTEM ANALYSIS

PROCUREMENT

RESEARCH AND DEVELOPMENT

DEFINITIONS

AN OR/SA SPECIALIST IS HIGHLY TRAINED AND SKILLED INDIVIDUAL WHO HAS THE ABILITY TO CONDUCT DETAILED OR/SA STUDIES. HE MUST POSSESS A GRADUATE DEGREE IN OR/SA OR A RELATED DISCIPLINE, OR HAVE 1 YEAR'S EXPERIENCE OR FORMAL ON-THE-JOB TRAINING IN OR/SA.

AN OR/SA EXECUTIVE IS AN INDIVIDUAL WHO HAS A PRACTICAL WORKING KNOWLEDGE OF OR/SA TECHNIQUES AND HAS THE ABILITY TO EVALUATE OR/SA STUDIES. THIS REQUIRES, AS A MINIMUM, COMPLETION OF SHORT-COURSE-TYPE TRAINING IN THE PHILOSOPHY AND APPLICATION OF OR/SA TECHNIQUES, OR EQUIVALENT EXPERIENCE.

THE TERM, "EXECUTIVE", ACTUALLY REFERS TO A SKILL LEVEL; IT DOES NOT NECESSARILY RELATE TO MILITARY GRADE OR THE LEVEL OF AUTHORITY WITHIN AN ORGANIZATION.

ARMY OR/SA POSITIONS APPROVED

	SPECIALIST	EXECUTIVE	TOTAL
DEPARTMENT OF DEFENSE	41	51	92
ARMY STAFF	146	180	326
MAJOR COMMANDS	197	256	453
TOTAL	384	487	871

PERCENTAGE DISTRIBUTION

	SPECIALISTS	EXECUTIVES	TOTAL
DEPARTMENT OF DEFENSE	11%	10%	11%
ARMY STAFF	38%	37%	37%
MAJOR COMMANDS	51%	53%	52%
TOTAL	100%	100%	100%

ARMY OR/SA POSITIONS

	SPECIALISTS	EXECUTIVES	TOTAL
DOD	41	51	92
OVCofSA	56	12	69
DCSOPS	12	29	41
DCSLOG	3	7	10
DCSPER	8	4	12
COA	15	5	20
CRD	14	9	23
ACSI	8	16	24
ACSFOR	20	74	94
ACSC-E	2	14	16
CofE	1	3	4
TAG	3	1	4
PMG	1	4	5
OPO	3	2	5
USACDC	109	144	253
USAMC	31	63	94
USCONARC	12	25	37
USAREUR	0	2	2
USARPAC	17	9	26
USASA	9	5	14
USARADCOM	11	6	17
USAWC	3	0	3
USMA	5	2	7
TOTALS	384	487	871

OR/SA SPECIALIST TRAINING

OPERATIONS RESEARCH (ENGINEERING)	OPERATIONS RESEARCH (BUSINESS)
NAVAL POST-GRADUATE SCHOOL	AMERICAN UNIVERSITY
PURDUE	TULANE
OHIO STATE	INDIANA
MICHIGAN STATE	ALABAMA
GEORGIA TECH	WISCONSIN
M. I. T.	BABSON INSTITUTE
ARIZONA STATE	R. P. I.
ALABAMA	GEORGE WASHINGTON
STANFORD	PENN (WHARTON)
PENNSYLVANIA	
SOUTHERN ILLINOIS	**SYSTEMS ANALYSIS**
RESEARCH ANALYSIS CORP	
STANFORD RESEARCH INST	INSTITUTE FOR DEFENSE ANALYSES
	STANFORD
	TULANE

OR/SA EXECUTIVE TRAINING

OR/SA EXECUTIVE COURSE
U. S. ARMY MANAGEMENT SCHOOL
FORT BELVOIR, VIRGINIA

NAVAL POST-GRADUATE SCHOOL
MONTEREY, CALIFORNIA

ARMY RESEARCH OFFICE
OFFICE, CHIEF OF RESEARCH AND DEVELOPMENT
ARLINGTON, VIRGINIA

ARMY MATERIEL COMMAND (MATHEMATICA)
FORT LEE, VIRGINIA (PRINCETON, NEW JERSEY)

COMPTROLLER OF THE ARMY
U. S. ARMY MANAGEMENT SCHOOL
FORT BELVOIR, VIRGINIA

REQUIREMENTS FOR EDUCATION IN OPERATIONS RESEARCH IN THE U. S. MARINE CORPS

LTCOL T. R. ABERNATHY, U.S.M.C.
HEADQUARTERS, U. S. MARINE CORPS

As I am sure all of you know, in terms of manpower, the Marine Corps is the smallest of the four services. This carries with it both advantages and disadvantages. For example, nearly 60% of our total manpower is in our division/wing teams. Another 30% is in the individuals line-training, transient status, and so on. This doesn't leave much in the way of either percentages or actual numbers with which to build a complex or complicated overhead structure. The net result is that we in the Marine Corps do have a most gratifyingly simple structure when compared to any of the other three services. It is not too difficult to isolate those units or offices of the Marine Corps where we may with some profit place an analyst of one kind or another.

On the other side of the same coin, the small size makes it very important that we do identify the billets accurately and promptly. If we were larger, if we had a larger overhead structure then we would have a pool of talents which could to some extent be drawn upon to fill billets as they were identified. As it is, when a billet is identified, more often than not there is no one properly trained or immediately available to fill it. The result is that some billets wait for a period of several years before they are filled because we must either train a new man or wait till someone who is properly trained is available for transfer to the billet.

I indicated a moment ago that we find it comparatively easy to idenfity billets where some kind of analytical work must be done. The difficulty is to determine what kind of an analyst is needed, for the true nature of the problems to be solved is not always evident. What appears to be a management problem may well be one in data processing. What is described as an operational problem could turn out to need nothing more than the application of better management techniques, and so on.

To lay the groundwork for an expression of what the Marine Corps needs in the way of education in operations research I want to discuss for a moment the problems encountered at various echelons within a service or,more properly, within the three military departments. The chart you see as figure 1 is generalized in nature. It shows stylized levels within a department and lists some of the problems or subjects for analysis that present themselves at the various levels. I have broken the service headquarters level problems down into two categories because I think that it is almost true now that the services literally keep two sets of personnel in headquarters. One set of people keeps the service functioning on

this year's budget and deals with internal problems. Another set deals with the future-year problems, which means largely with OSD. Where there aren't two different people, at least the one man will put on two different hats when dealing with subordinate service levels and when dealing with OSD.

The point I want to make here is that the problems at lower echelons are almost purely operational in nature. At these levels, military operations are considered directly and examined first-hand with the aim of improving the conduct of war. The economics of the situation receive little consideration or are often childishly simple in nature. As we look at higher echelons, we tend to find that operational problems are considered less directly and economic or management problems come in for progressively more attention. The real world of operations never completely fades from the picture, even at the DOD level, but it is considered less and less directly as an entity in itself and more and more as an input to or a facet of a problem in economics or management. I do not mean that the economic or management problem is not real-world too, but it considers factors that are often outside the scope of the military, namely, the national economy. Also, at this level the problem is very nearly the exact reverse of the one at the lower service levels. Here, the economic considerations are many and complex and the details of operations are either lost from consideration or made almost childishly simple.

Now, where does this leave us? The chart indicates that the services have problems that range from the purely operational to almost the purely economic, and that every gradation between the two extremes can occur. The question that arises in a natural way is "should the operations analyst be educated or expected to cope with the full spectrum of these problems?"

The answer, or at least as far as the Marine Corps is concerned, is "No". We have available to us two different courses in the operations analysis/systems analysis area. One is the one-year Defense Systems Analysis Course given by the University of Rochester and the Center for Naval Analyses. Students in this course receive only a smattering of technique courses in operations research. The bulk of the coursework centers on economics and at the end of the course they are awarded a master's degree in economics. This course has two very attractive features: it furnishes an adequate educational background for work in the DOD interface, where "alternatives" and "cost effectiveness" are the bywords; and it only takes 15 months to complete.

This last point harks back to a problem I discussed at the very beginning of my talk. The Marine Corps must try and manage its manpower as carefully as possible for there is little, if any, slack in the system. If a one-year course will accomplish the task, then we will not send a man to a course that takes longer. Thus, you will

find that where possible, and primarily at the Headquarters, Marine Corps level, we have designated billets to require attendance at the University of Rochester/Center for Naval Analyses Defense Analysis course. There are about 20 such billets at present, with the number growing at a rate of about five each year. Since the OA content of this course is minimal, the graduates are not really considered capable of across-the-board substitution in place of fully trained operations analysts. Such substitution as is possible is limited to billets where the analysis requirements lean towards economics or defense allocation problems.

The remaining identified billets, about 70 in number, call for attendance at the other course that is available to the Marine Corps. This other course is the two-year Operations Analysis/Systems Analysis Course at the Naval Postgraduate School. We do not do this, of course, but we still have requirements to meet. Let me briefly cover these requirements.

At the DOD interface, we have only five billets deemed to require OA training. The officers assigned work primarily in study groups or as representatives to study offices. The small number here contrasts sharply with the roughly 20 billets calling for the Defense Systems Analysis Course. For internal Headquarters, Marine Corps problems and functioning, there are about 22 billets calling for OAs. The tasks assigned deal primarily with improvments to our own operational management problems.

The largest single group of billets is in the Fleet Marine Forces, with some 28 identified billets including three with the Marine Corps forces in Vietnam. These officers deal with the problems of the operating forces.

We have 15 other billets in miscellaneous categories; nine in the R and D effort, assigned to the Landing Force Development Center at Quantico; three teaching in schools; and three officers assigned to program the Marine Tactical Data System, which is designed as the air control system for aircraft in the amphibious objective area.

I want to point out that of the 70 billets, 31 (or about 44%) are directly concerned with the analysis of on-going military operations in the field. Twenty-two (or about 30%) are concerned with internal non-tactical operational problems. Nine are involved with the R and D effort, primarily with the OA work in support of studies. Only eight are not directly or indirectly concerned with the analysis of operations, either tactical or non-tactical.

Therefore, it is reasonable to state that the primary requirement for the Marine Corps is an analyst with a classic operations analysis education; that is, an education strong in science, math or engineering plus OA methodology. Since our main concern is operational analysis, the OA should have sufficient time to become thoroughly competent in his major interest field. For most military officers this implies a full two-year course. It takes just about all of one semester to redevelop the art of studying, and perhaps part of another semester to recall most of what has gone by the boards since undergraduate days. This leaves a bare minimum of time for genuinely productive classwork and a thesis project that demonstrates adequately that the individual is really capable of independent research.

This, then, represents a thumbnail sketch of the educational requirements for the Marine Corps in the operations analysis/systems analysis area.

MARINE CORPS OPERATIONAL ANALYSIS BILLETS

. DOD	-	5
. HQMC	-	22
. FMF	-	28
. R&D	-	9
. Schools	-	3
. MTDS	-	3
Total		70

FIGURE 1

SMALL UNITS	LARGE UNITS	UNIFIED/ SPECIFIED COMMANDS	SERVICE LEVEL (IN-HOUSE)	SERVICE LEVEL (DOD)
.Detailed Tactics	.Stylized Tactics	.Strategy	.Force Structure	.C/E Studies
.Procedures And SOP	.Weapon System Interactions	.Force Allocations	.Weapon System Selection	.MGMT Reports
.Weapon Characteristics	.Logistics (Supply and Allocations)	.Logistics (Allocation and Budget)	.Management Procedures	.PPBS

COMMENTS AND CONCLUSIONS

Although the services have been increasing their requirements for OR/SA trained officers, both specialists and executive level, due to the shortage of people and money the quotas for educational programs are not being met by the various services. It will take many years if current trends continue before the number of trained people catch up with requirements. Utilization of OR-trained people is slightly different in the various services; for example, the Marine Corps has a higher percentage of positions at the operational type analysis billets.

When the services have sufficient trained officer analysts working with skilled civilian analysts as a team, the overall quality of OR studies should improve.

MICRO-OR/SA

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SUMMARY

A study concept, coined MICRO-OR/SA or short, small, immediately useful applications of OR/SA methodology, is presented by definition and example. The examples of MICRO-OR/SA study products are--

1. A descriptive model of the Saigon Area Port Clearance System which allowed identification of the critical problem areas and stimulated creation of a Movements Control Center charged with the responsibility of optimizing overall system efficiency.

2. An input-output model of the Aviation Materiel Management Center (AMMC) aircraft repair parts supply system in Vietnam which was implemented as a principal management tool.

3. A value judgment model designed to relate individual subjective judgments on the value of equipment system parameters to an ultimate criterion, defined as Value to the Army (VTA).

The purpose of this paper is to propose wider use of this technique to improve Army systems at the operational level.

INTRODUCTION

Most military OR/SA studies have concentrated efforts at a high level using sophisticated and expensive techniques. In many cases, the study cost, in dollars and time, has outweighed the benefits derived. The purpose of this paper is to propose a quantitative study concept with potential application at the operational level. The concept is MICRO-OR/SA or small, short, immediately useful studies that rely on simple techniques and produce immediately useful results.

MICRO-OR/SA CHARACTERISTICS

A MICRO-OR/SA study, by definition, exhibits the following characteristics:

1. A small investment in resources compared to the probable return in benefits accruing due to implementation of the study recommendations.

2. A compressed study schedule with the intention of continuous follow-through until the study recommendations are either implemented or rejected.

3. Use of existing data reflecting the short study schedule and required accuracy of the data. Computations are by hand or slide rule and carried to minimum essential accuracy.

4. Although the data and calculations are less accurate than in a more conventional study, the conclusions and necessary actions are so obvious that the model error is irrelevant.

5. The study, to include concepts, data acquisition, methodology, analysis, and presentation, is conducted by a small group. This requires individuals who combine a basic understanding of the system, preferably as a result of on-the-job experience, with a capability to utilize rudimentary OR/SA tools. An example is that many data acquisition on-the-spot decisions are based on a feel for the sensitivity of the model to the particular data set.

6. Simple techniques of presentation to insure understanding and implementation by decision-makers at the operational level.

MICRO-OR/SA BY EXAMPLE

There are literally thousands of Army systems problems spread across a wide geographical and functional spectrum that are amenable to MICRO-OR/SA analysis. MICRO-OR/SA studies of these systems will result in dollar savings many times greater than the investment. The MICRO-OR/SA concept is best illustrated by actual examples. This paper presents three such examples, selected because of their distribution across the geographical and functional spectrum.

EXAMPLE 1
DESCRIPTIVE MODEL
SAIGON AREA PORT CLEARANCE SYSTEM

Background. During late 1965 and early 1966, the massive buildup of U.S. Forces in Vietnam caused severe backups at the Saigon docks. By the summer of 1967, the port backlogs had been eliminated and cargo was flowing smoothly through the Saigon and newly constructed Newport facilities. However, the cost of the clearance operation was excessively high. The port clearance operation was primarily accomplished utilizing U.S. contractor vehicles and Vietnamese drivers. Although all consignees were within 20 miles of the ports, the average trip turn-around-time (TAT) was estimated to be in excess of 10 hours. This fact prompted the Director of Transportation, 1st Logistical Command, who had overall supervision of the port clearance system, to initiate a study designed to describe and analyze the Saigon Area Port Clearance System. Limited time and resources dictated a small study effort designed to highlight the system sufficiently to identify the causes of the excessively high TAT.

Model Development. The system consisted of several competing subsystems (the port complexes, the vehicle contractors, the Vietnamese drivers, and innumerable consignees) each attempting to optimize the operation of their particular subsystem. The purpose of the system model was to stress the necessity of controls, on a daily basis, that would allow a more efficient overall system operation. Since the U.S. contractors and Vietnamese drivers were paid on a vehicle-hour basis and all truck loads were essentially the same size, it was decided to use the average TAT as the system measure of effectiveness (ME). Data on the number of trips to each consignee was

available; however, the necessary TAT's were available only for the major consignees. This required formulation of the available data into subsystems consisting of major consignor-consignee combinations as shown in table 1.

Since the total number of trips per month (TPM) and the total number of daily truck dispatches per month was known, a system average TAT could be calculated. (31,270 TPM ÷ 11,354 daily truck dispatches per month = 2.8 trips per day, or an average TAT of 8:30) This allowed calculation of the remaining unknowns--the number of "Other" trips (14,670) and the average TAT (5:00) associated with the "Other" trips. A complete system model is illustrated in table 2. The data of table 2 confirmed the suspicion that a few of the subsystems with excessively high TAT were responsible for the unacceptably high system TAT.

Model Uses. The model was simplified, pictorially depicted (figure 1), and the effects of specific remedial actions on the system ME, TAT, and the consequent cost savings were determined. Three areas contributing to the high system TAT were identified:

1. The in-out time at storage area 208 (from when a truck arrived until it was off-loaded and departed) averaged 5:15. The contributory factors were--irregular flow from the ports causing long waiting lines, insufficient off-loading equipment, and inadequate supervision at night to insure that drivers kept their vehicles moving (many slept the night away in a remote area of 208). It was felt that proper remedial actions could reduce the 208 in-out time from 5:15 to 2:15. The effect upon the system TAT is shown in table 3, Action A, and the resultant dollar savings in table 4. The cost savings were based on contract costs of \$3.60 per truck hour or \$115,000 per month per hour of system TAT (\$3.60 x 31,270 TPM).

2. The in-out time at the 506 Field Depot (FD) was 4:40. Again, it was felt that corrective actions could reduce this to 2:40 resulting in a further decrease of system TAT and additional dollar savings (table 3, Action B).

3. By also reducing port in-out time by one hour, it would be possible to effect a cumulative dollar saving of approximately \$200,000 as shown in table 4.

Comments. The study required approximately 20 professional man-days and 5 clerical man-days. It was presented to representatives of all involved headquarters and to the Commanding Generals of Saigon Support Command and 1st Logistical Command. It stimulated immediate remedial actions in the areas indicated and, within a month, resulted in creation of a 20-man Movements Control Center to control and regulate the independent subsystems so as to optimize overall system efficiency.

MAJOR CONSIGNEE TAT AND TRIPS PER MONTH (TPM)		
SUBSYSTEM	TAT	TPM
Newport to 208	11:40	5,430
Saigon Port to 208	12:55	3,380
Other to 208	12:00	2,200
Newport to 506 FD	10:30	1,120
Saigon Port to 506 FD	10:30	2,350
Newport to B&B	9:10	280
Saigon Port to B&B	10:30	1,840
TOTAL TPM		16,600

Table 1

DESCRIPTIVE MODEL SAIGON AREA PORT CLEARANCE SYSTEM			
(1) SUBSYSTEM	(2) TAT	(3) TPM	(4) (2) x (3)
Newport to 208	11:40	5,430	63,352
Saigon Port to 208	12:55	3,380	43,670
Other to 208	12:00	2,200	26,400
Newport to 506 FD	10:30	1,120	11,760
Saigon Port to 506 FD	10:30	2,350	24,675
Newport to B&B	9:10	280	2,565
Saigon Port to B&B	10:30	1,840	19,320
Other	5:00	14,670	74,053
TOTALS/AVERAGE	8:30	31,270	265,795

Table 2

TAT REDUCTIONS SAIGON AREA PORT CLEARANCE SYSTEM								
MODEL			ACTION A		ACTION B		ACTION C	
1 Subsystem	2 TPM	3 TAT	4 Reduce 208 In-out Time 5:15-2:15	5 Product 2x4	6 Reduce 506 In-out Time 4:40-2:40	7 Product 2x6	8 Reduce Ports In-out Time 4:00-3:00	9 Product 2x8
Newport & Saigon to 208	8,810	12:10	9:10	80,700	9:10	80,700	8:10	72,000
Other to 208	2,200	12:00	9:00	19,800	9:00	19,800	9:00	19,800
Newport & Saigon to 506	3,470	10:30	10:30	36,500	8:30	29,500	7:30	26,000
Newport & Saigon to B&B	2,120	10:20	10:20	21,900	10:20	21,900	9:20	19,800
Others	14,670	5:00	5:00	73,300	5:00	73,300	5:00	73,300
TOTALS/ AVERAGES	31,270	8:30	7:30	232,200	7:00	225,200	6:45	210,900

Table 3

TAT REDUCTION DOLLAR SAVINGS SAIGON AREA PORT CLEARANCE SYSTEM			
Action	System TAT Reduction	Monthly $ Savings	Monthly Cumul $ Savings
A	01:00	115,000	115,000
B	00:30	57,000	172,000
C	00:15	28,000	200,000

Table 4

INPUT-OUTPUT MODEL
SAIGON AREA PORT CLEARANCE SYSTEM

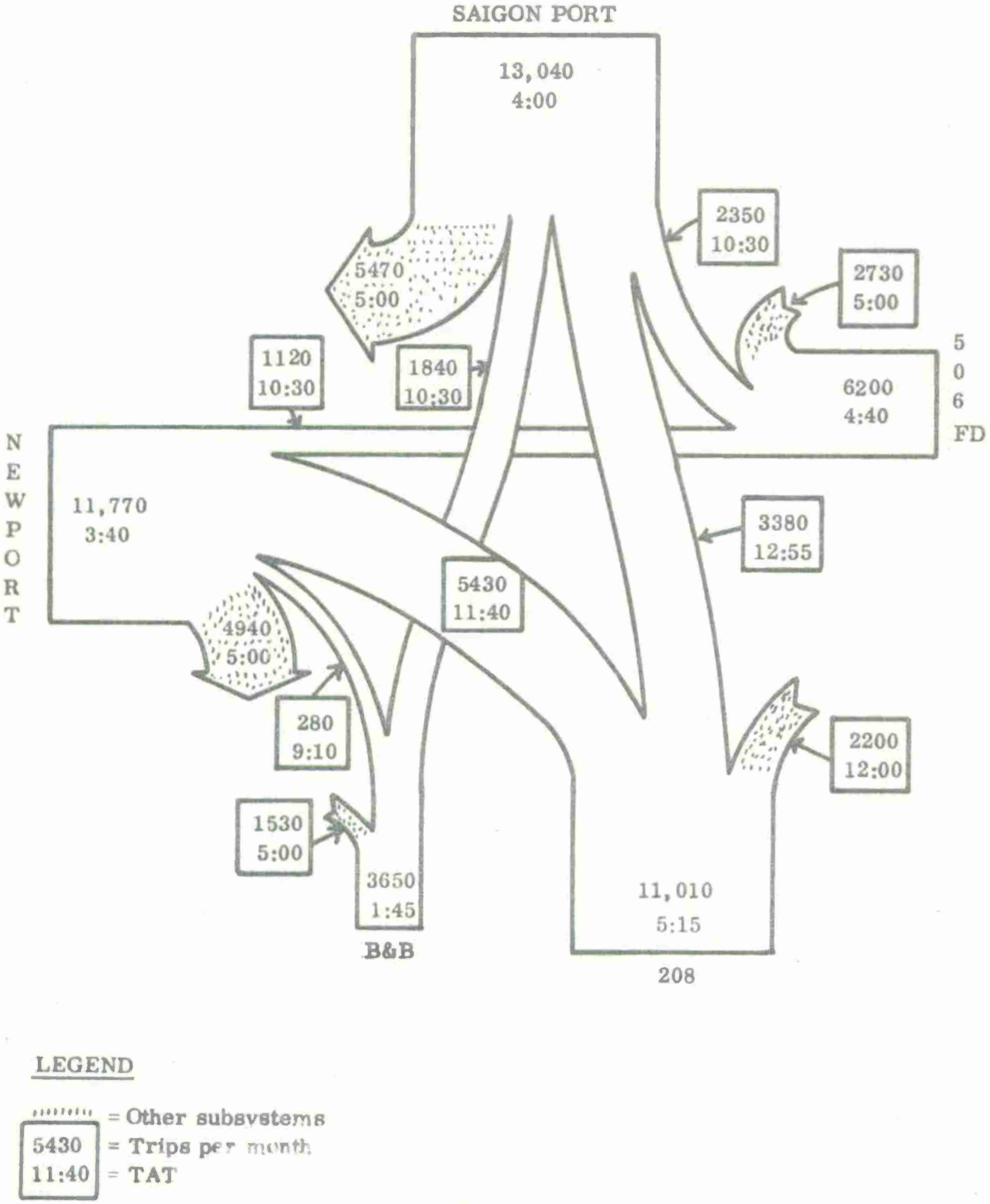

Figure 1

EXAMPLE 2
INPUT-OUTPUT MODEL
AMMC AIRCRAFT REPAIR PARTS SUPPLY SYSTEM

Background. All Army aircraft repair parts in Vietnam are processed by the Aviation Materiel Management Center (AMMC). By the summer of 1967, their volume had increased to over 50,000 requisitions per month. The existing management tools were crude. There was a feeling that a more comprehensive management approach was required which would give an over-all view of the system and allow determination of a unique measure of effectiveness (ME).

Model Development. Although a wealth of data was available, it was spread throughout the functional departments of AMMC and was based on varying accounting periods. Data was accumulated monthly, weekly, daily, and by computer processing cycle. The model was developed by identifying the possible paths of a requisition through the system and associating with each path a requisition volume and a processing time. The flow diagram of figure 2 was used as a guide to develop the schematic of figure 3 which was simplified into the pictorial and tabular models of figure 4 and table 5.

Model Uses. The adoption of the model as a management tool was premised partially on its use as a briefing vehicle and as an example of systems analysis at work. However, the primary purposes were--

1. Statistical--as a description of the AMMC system to measure progress attained. The average requisition System Processing Time (SPT) was chosen as the most appropriate system ME. The necessary data was machine-generated each month and a pictorial schematic of the model was created so as to provide a chronological summary of AMMC system operation.

2. Managerial--in that the model would allow testing the merit (model output) of particular management actions (model input). As a specific example, the following actions were taken to reduce the 6.9 day warehouse "prepare for shipment" time:

a. Programming machine output in bin location order rather than stock number order to facilitate "pick and pack."

b. Increasing available packing room area by convincing the Army engineers (using model output) that the additional space would save a considerable amount of money.

c. Hiring additional personnel to better handle the "pick and pack" requirement.

d. Increasing command emphasis in the warehouse area.

FLOW DIAGRAM
AMMC REQUISITION PATHS

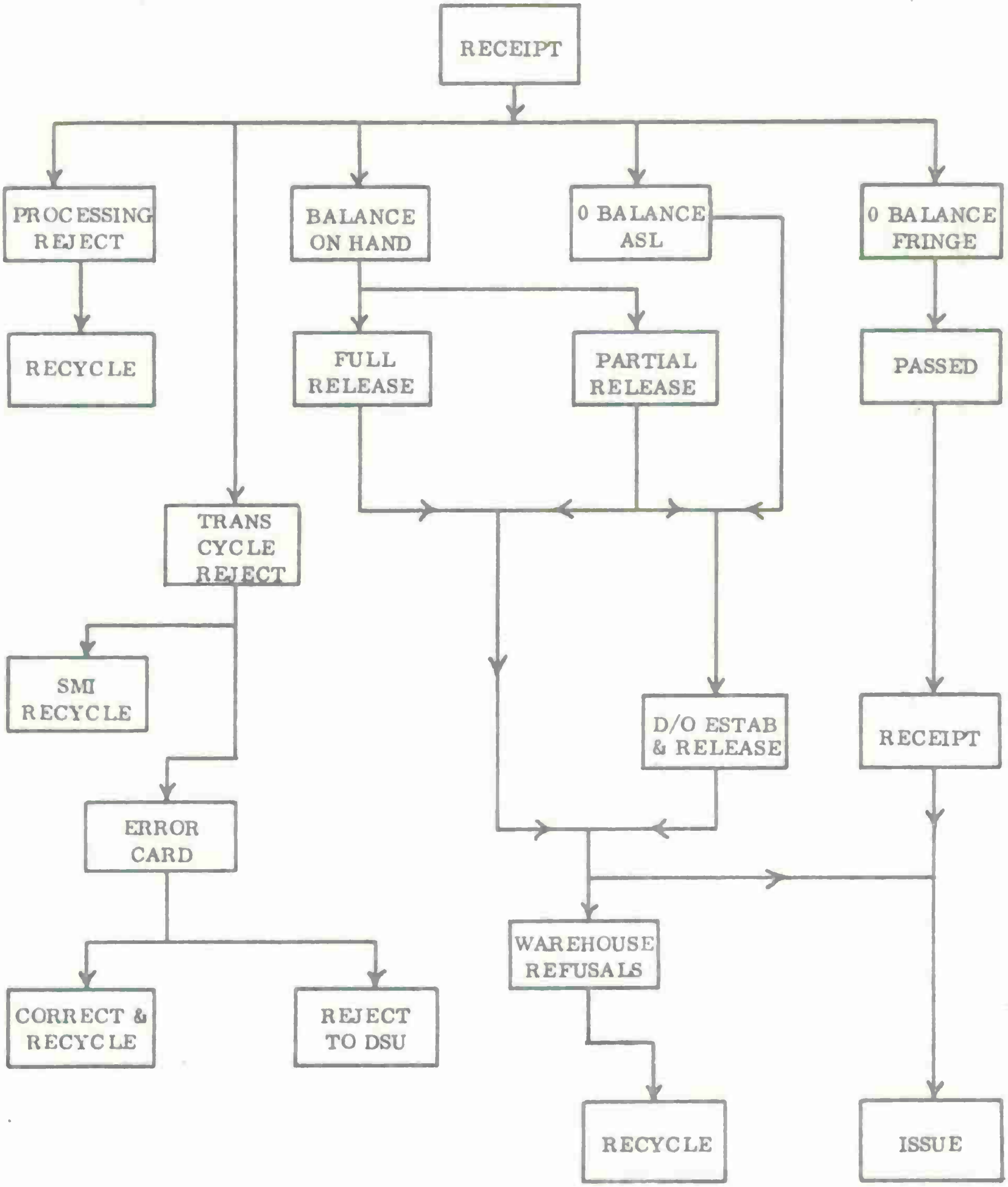

Figure 2

PICTORIAL SCHEMATIC
AAMC REQUISITION PATHS

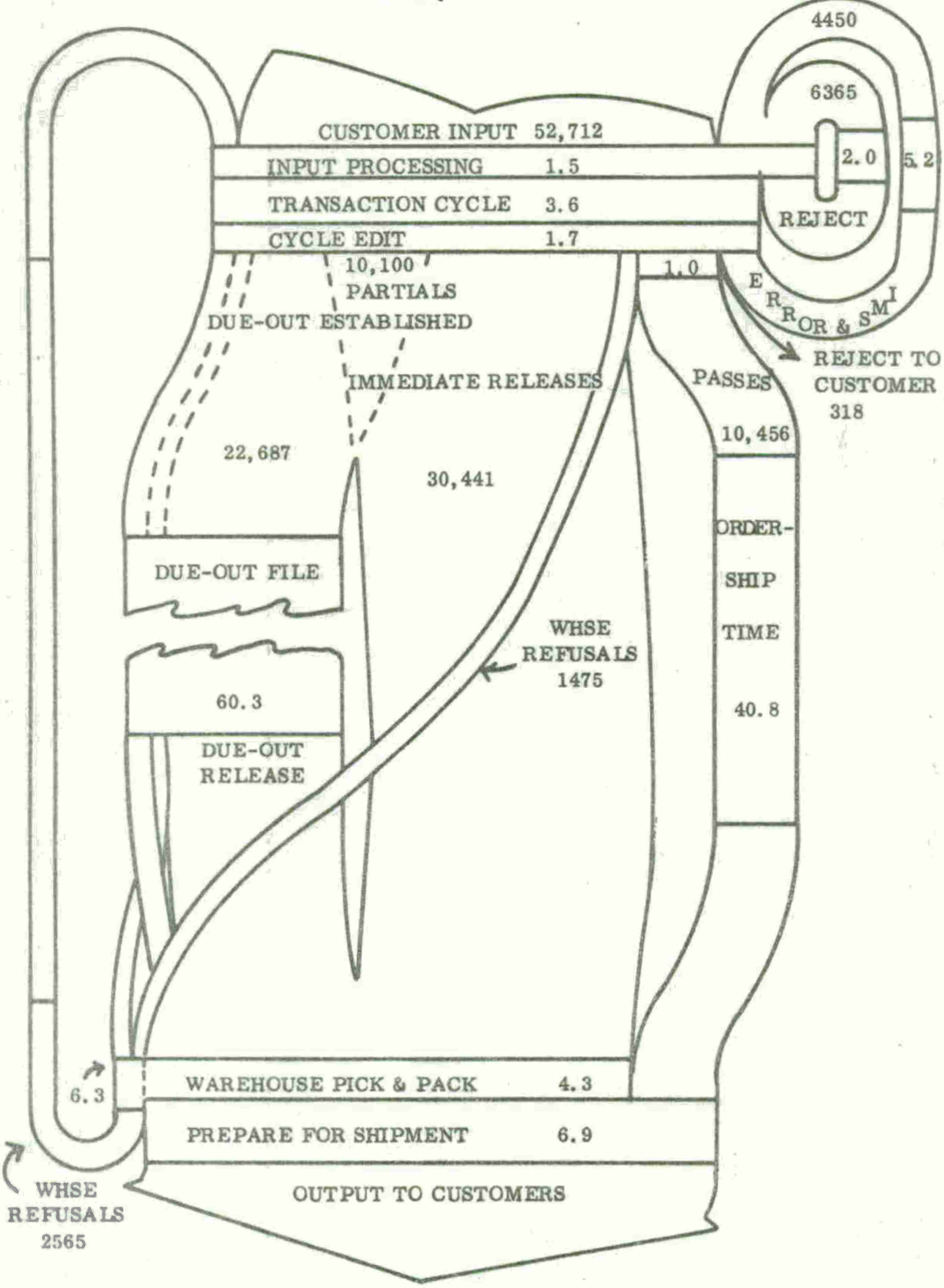

Figure 3

INPUT-OUTPUT MODEL
AMMC AIRCRAFT REPAIR PARTS SUPPLY SYSTEM

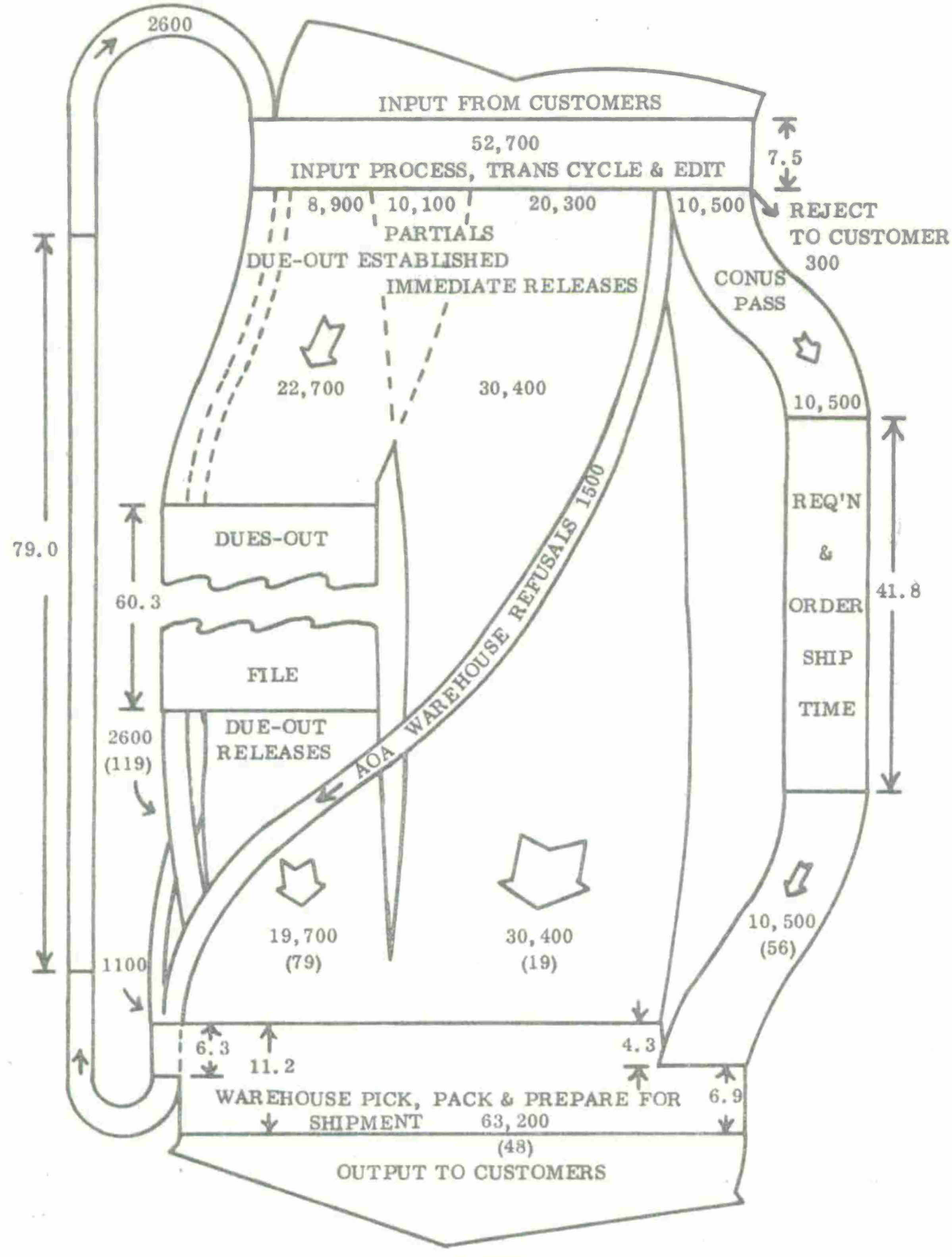

Figure 4

Within two months, these actions caused a 5 day reduction in warehouse "prepare for shipment" time, consequently reducing overall SPT by a like amount. Five days of aircraft repair parts in Vietnam were worth approximately $9 million, or, at 6% annum, a capital saving of $45,000 dollars per month.

INPUT-OUTPUT MODEL AMMC AIRCRAFT REPAIR PARTS SUPPLY SYSTEM		
Type Issue Subsystem	No. of Issues	Avg Days In System
Former Warehouse Refusal & Issue	2,600	119
Due-out File Release & Issue	19,700	79
Immediate Release & Issue	30,400	19
Passing Action Receipt & Issue	10,500	56
TOTAL/GRAND AVERAGE	63,200	$\boxed{48}$

Table 5

Comments. The study required 15 professional man-days and ten clerical man-days. It was immediately implemented as an AMMC management tool. Within 30 days, it had proven invaluable in identifying problem areas and documenting the improvement caused by specific corrective actions.

EXAMPLE 3
VALUE JUDGMENT MODEL
ARMY EQUIPMENT SYSTEMS

Background. In late 1967, a study was conducted by the U.S. Army Combat Developments Command Aviation Agency to determine the optimal characteristics, or parameters, of an Army STOL utility airplane. A Value Judgment Model was developed to function as a "filter" to narrow the range of each parameter to be considered. Although developed for this purpose, the model is general in nature and applicable to any Army equipment system.

Model Development. The model was created by asking a group of experienced, senior Army officers, primarily aviators, to establish, in a quantitative format, the relationship of the equipment parameters to a criterion defined as "Value to the Army" (VTA). The Value Judgment Board (VJB) consisted of 45 participants ranging in rank from Major to Lieutenant General. They were given the background of the study effort, a feel for the technical tradeoffs involved, and asked to create a set of individual VTA-parameter curves; considering the intra- and inter-parameter relationships to the criterion function, VTA. The results for the STOL utility airplane are shown in a set of VTA-parameter curves (figure 5). The heavy central line of each graph is the mean of the individual curves of 45 participants. The limits of the cross hatched area represent ± one standard deviation.

Model Uses. Particularly in smaller studies of this type, time and money constraints militate against a more traditional methodology of using a large set of representative missions to test a number of parametric equipment designs. A primary use of the Value Judgment Model is as a "filter" to reduce the number of parametric equipment designs to a manageable level. However, in its own right, the model has some distinct uses. These uses assume that the importance of the study (i.e., size of buy or degree of difference between candidates) is not sufficient to warrant expenditure of large quantities of time and money. The model uses are as follows:

1. Identification of an optimal set of equipment parameter magnitudes. By selecting a set of parameter magnitudes that maximize total VTA, a theoretical optimal equipment system can be defined. Depending on the shape of a particular VTA-parameter curve, this may result in a unique magnitude of the parameter or a narrow optimal range.

2. Ranking of equipment candidates. The model allows the relative ranking of actual equipment candidates cardinally ordered according to their total units of VTA. Dividing a candidates VTA by its unit life cycle cost results in a cost-effective ordering according to units of VTA per dollar.

3. Evaluation of Inter-parameter tradeoffs. Since it is probable that the optimal set of parameter magnitudes is not technically feasible, the model allows a determination of a sub-optimal feasible set that maximizes VTA within the limits of the current "state of the art."

Comments.

1. The specific model illustrated in figure 5 was created utilizing approximately 60 professional man-days and 20 clerical man-days. It allows a rapid convergence to a small range for each parameter. The reduced range of each parameter can then be considered for intensified analysis.

2. The general model, created and approved at the appropriate level, would be an invaluable tool to provide general guidance to industry as to how Army equipment users feel about the relative importance of the equipment parameters.

3. The traditional approach to studies of this type is to create a wargames scenario hopefully representative of future worldwide commitments. This REQUIRES VALUE JUDGMENTS. Parametric equipment designs are then tested in the scenario and a number of ME evaluated and somehow aggregated to determine the relative worth, or VTA, of each parametric design. The decisions as to which ME to use REQUIRES difficult VALUE JUDGMENTS. The determination of the intra-ME relationship to VTA (i.e., linear, or if non-linear, its shape) REQUIRES VALUE JUDGMENTS of the most difficult type. The inter-ME relationships, or weighting factors, necessary to justify additivity REQUIRE VALUE JUDGMENTS. The VJB concept does not ignore the doctrine that a piece of equipment must be designed to optimally accomplish its future set of mission requirements. Implicit, and primary, in every value judgment rendered by a board member is consideration for this mission set as he envisions it. The VJB model is asking his "computer" (programmed with his previous experience and the constraints of the particular study) to relate each parameter to VTA utilizing every real-world consideration, of which he is aware, that bears on the problem. Essentially, the VJB concept collapses all value judgments into a single controlled procedure that goes directly to the ultimate criterion, VTA, and relates the equipment parameters in a direct, overt manner.

CONCLUSIONS

The prime movers of military OR/SA have been the Navy and Air Force because their basic missions are keyed to a small number of large, expensive equipment systems. These type systems are particularly amenable to rigorous, sophisticated analysis. This is not true of the Army; and an Army OR/SA program must recognize this fact, sacrifice professional "neatness," and expand into the many operational level systems where real money can be saved. Although the problem of implementing a MICRO-OR/SA concept at the operational level is a difficult one, the examples presented in this paper illustrate that the problem is not insurmountable.

STOL UTILITY AIRPLANE
VTA-PARAMETER CURVES

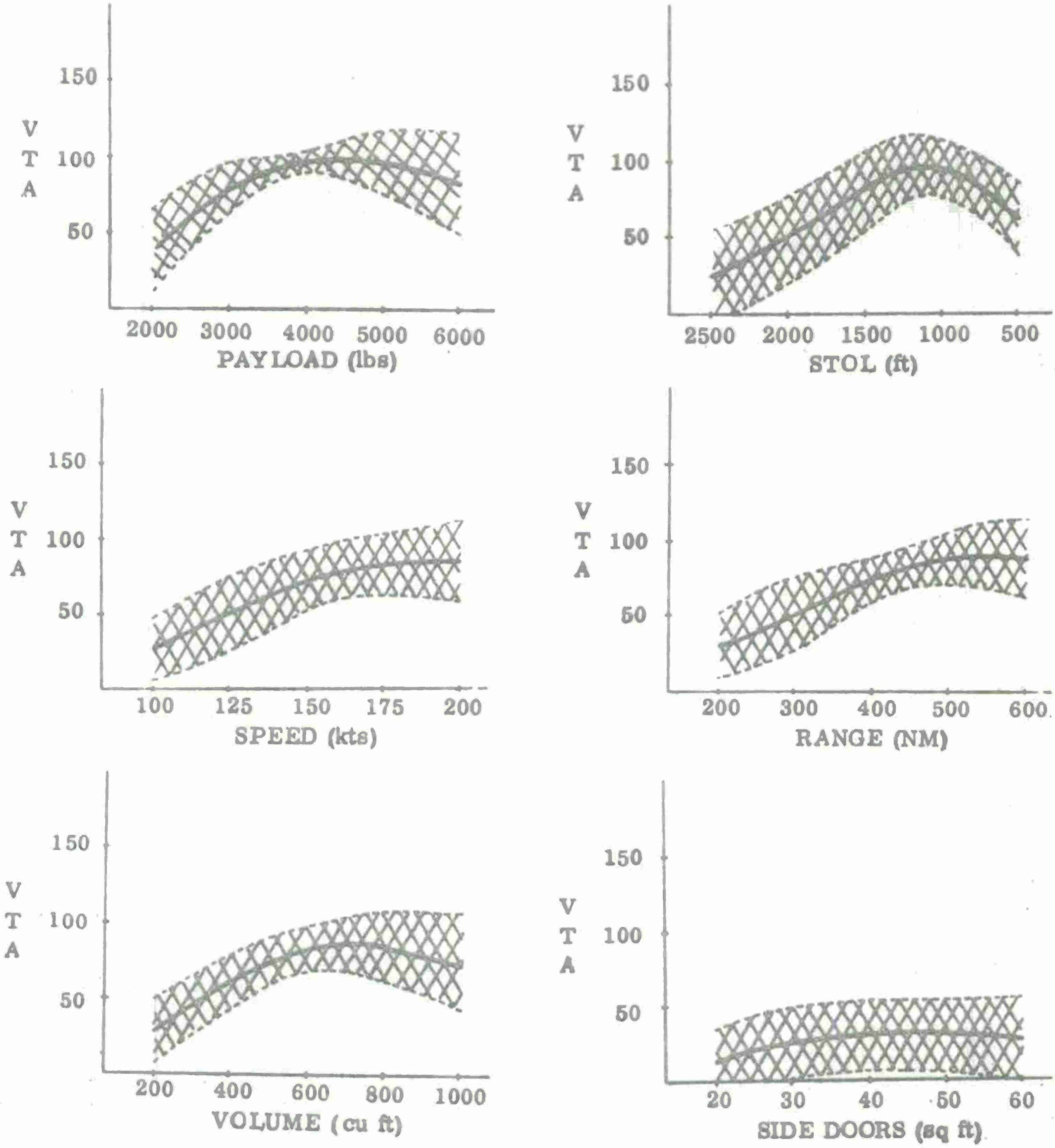

Figure 5

STOL UTILITY AIRPLANE
VTA-PARAMETER CURVES

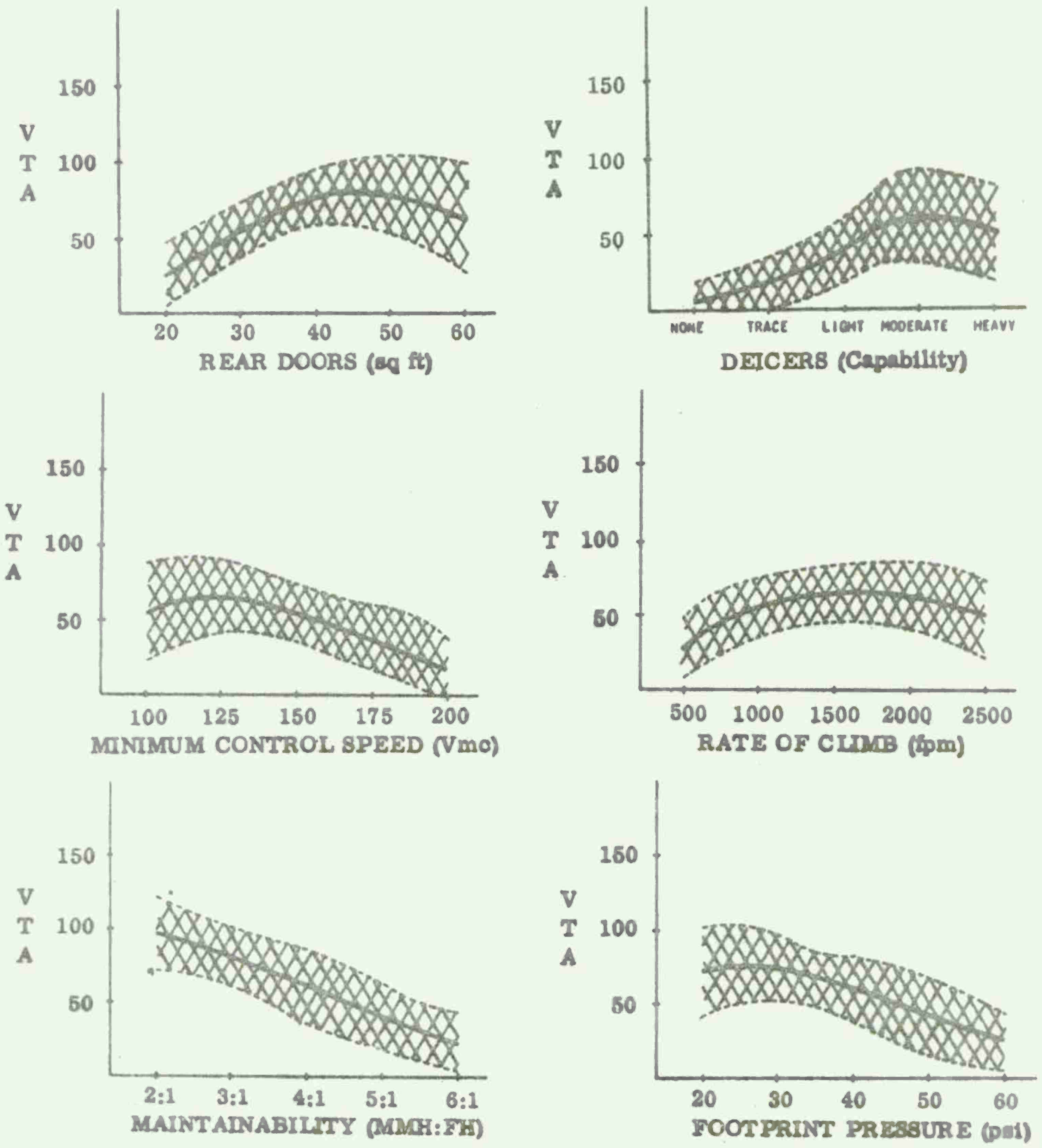

Figure 5 (cont)

RATIONALE AND MEASURES OF EFFECTIVENESS USED TO EXAMINE MARINE CORPS FIRE TEAM SIZE AND ORGANIZATION

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Background

During the spring of 1966 the Marine Corps Landing Force Development Center was responsible for conducting an evaluation of the Stoner 63 Weapons System. (USMC Project 30-65-05). The Stoner 63 Weapons System consists of a family of small arms which fire a 5.56mm (.223 caliber) bullet. There is a basic component group which is common to all weapons of the family. Various barrels, feeding mechanisms and mounts or grips are added to the basic component group to configure six different weapons: an assault rifle, a carbine, a tripod-mounted medium machine gun, a belt-fed light machine gun, a magazine-fed light machine gun (automatic rifle), and a fixed machine gun (for use in tanks or aircraft). The Marine Corps was particularly interested in the Stoner 63 System because of the simplified training and logistics that would result from common parts and ammunition. In addition the Stoner System, like the M-16, has the light-weight advantage inherent in a system using the .223 cartridge.

An evaluation of the Stoner 63 Weapons System was held at Camp Lejeune, N.C. in the spring of 1966. The tests conducted at Camp Lejeune were to determine the impact on the organization and tactics of the Marine Infantry Battalion if a family of weapons concept were introduced at the small arms level. The possibilities for reorganization that result from the ability to shift from one weapon configuration to another, from the ability to interchange parts between weapons and from the potential increase in individual capabilities are many. The test examined these possibilities to determine the most effective size and composition of the basic infantry element, the fire team. The point of departure for these considerations was the current Marine Corps organization.

If large variations from the four man fire team are excluded, there exist 74 fire team compositions to be considered. These possibilities are listed in Table I. Not all of the possibilities are reasonable or attractive. Certain of these combinations were excluded from testing by the following rationale.

Contributors to Effectiveness

Consider the current fire team organization and excursions from it on the basis of the following desirable characteristics.

Firepower
Target Acquisition Capability
Sustainability
Mobility
Controlability
Simplicity

Let us further consider that the fire team is to consist of men armed with rifles and automatic weapons, assigned such primary duties as fire team leader, automatic weapon carrier, assistant automatic weapon carrier and rifleman/scout.

To maximize firepower and suppressive fire, it would be desirable to maximize the number of automatic weapons in the fire team, consistent with other considerations discussed below.

The ability of members of the fire team to acquire targets is an important determinant of the overall effectiveness of the fire team. Although each member of the fire team has the duty to acquire targets, the rifleman or scout has the principal responsibility to acquire targets without drawing return fire. His secondary duties involve supplementing the firepower of the team and other duties as appropriate.

The fire team leader's primary function is the command and control of his fire team in response to his squad leader's orders. He must be continually alert to changes in formation, issuance of orders, and

TABLE I

POSSIBLE FIRE TEAM/WEAPON COMBINATIONS

3 Men Alternative #	Mix	4-Men Alternative #	Mix	5 Men Alternative #	Mix	6 Men Alternative #	Mix
3-1	RRR	4-1	RRRR	5-1	RRRRR	6-1	RRRRRR
3-2	RRA	4-2	RRRA	5-2	RRRRA	6-2	RRRRRA
3-3	RRM	4-3	RRRM	5-3	RRRRM	6-3	RRRRRM
3-4	RAA	4-4	RRAA	5-4	RRRAA	6-4	RRRRAA
3-5	RAM	4-5	RRAM	5-5	RRRAM	6-5	RRRRAM
3-6	RMM	4-6	RRMM	5-6	RRRMM	6-6	RRRRMM
3-7	AAA	4-7	RAAA	5-7	RRAAA	6-7	RRRAAA
3-8	AAM	4-8	RAAM	5-8	RRAAM	6-8	RRRAMM
3-9	AMM	4-9	RAMM	5-9	RRAMM	6-9	RRRAMM
3-10	MMM	4-10	RMMM	5-10	RRMMM	6-10	RRRMMM
		4-11	AAAA	5-11	RAAAA	6-11	RRAAAA
		4-12	AAAM	5-12	RAAAM	6-12	RRAAAM
		4-13	AAMM	5-13	RAAMM	6-13	RRAAMM
		4-14	AMMM	5-14	RAMMM	6-14	RRAMMM
		4-15	MMMM	5-15	RMMMM	6-15	RRMMMM
				5-16	AAAAA	6-16	RAAAAA
				5-17	AAAAM	6-17	RAAAAM
				5-18	AAAMM	6-18	RAAAMM
				5-19	AAMMM	6-19	RAAMMM
				5-20	AMMMM	6-20	RAMMMM
				5-21	MMMMM	6-21	RMMMMM
						6-22	AAAAA
						6-23	AAAAM
						6-24	AAAAMM
						6-25	AAAMMM
						6-26	AMMMMM
						6-27	MMMMMM

R - indicates a rifle

A - indicates a magazine-fed automatic rifle

M - indicates a belt-fed light machine gun

distribution of ammunition. He must position himself within vocal and visual range of his squad leader. In addition he acts as a rifleman, but not to an extent detrimental to his principal function. His ability to acquire targets is severely restricted by these considerations.

The automatic weapon carrier's primary function is to provide firepower, as directed by the fire team leader. His target acquisition capability is at best marginal, since for protection, he is normally positioned innermost in the fireteam. Once assigned a target by the fire team leader, his attention is concentrated on his primary function of providing firepower.

The assistant automatic rifleman, if one is designated, is primarily concerned with insuring the sustainability of the firepower by assisting the automatic weapon carrier to clear stoppages, by delivering ammunition, and by supplementing fire with his own rifle. His ability to acquire targets decreases as the automatic weapon becomes engaged and firepower requirements increase. In the event the automatic weapons carrier becomes a casualty, the assistant assumes his duties, and his target acquisition capability is correspondingly reduced.

To determine an effective fire team organization, three principal functions - command and control, delivery of suppressive fire, and target acquisitions - and one capability - sustainability - must be considered. In a three man fire team or in a four man fire team with more than one automatic weapon, two of these principal functions must be assigned to a single individual, thus degrading both the man's principal function and the newly acquired one.

The demands of sustainability and mobility of the individual are contradictory. Increasing the amount of ammunition carried increases sustainability but decreases mobility and vice versa. The high expenditure rate of the automatic weapon requires that at least one assistant be provided for each automatic weapons carrier, if only to

carry extra ammunition. The exact number of assistants depends on the weight of the weapon and ammunition and a determination of the appropriate basic load. Further, there is a requirement within the basic infantry unit to be able to detach a man to return to some resupply point to obtain more ammunition and rations while the unit maintains a reasonable level of effectiveness on the firing line. Sustainability in the face of individual fatigue, high ammunition expenditure, and casualties are important considerations.

One of the most difficult problems in determining squad and fire team tactics is the determination of the ability of the individual to command and control. Thus a basic consideration is the degree of sophistication of the non-commissioned officers assigned as fire team leaders. This consideration probably eliminates fire teams with more than six men or more than two automatic weapons.

Implications for the Fire Team Organization

Table I lists possible fire team organizations excluding large variations from the present fire team. With the rationale discussed above, the number of alternatives was reduced to a number that could be considered feasible for testing.

The requirement that at least one automatic weapon be included in each fire team excludes alternatives 3-1, 4-1, 5-1 and 6-1 (see Table I). These are the alternatives which include only riflemen. The requirement that each automatic weapon carrier have at least one assistant eliminates possibilities 3-4 through 3-10, 4-7 through 4-15, 5-7 through 5-12 and 6-11 through 6-27. A requirement that the complexity of the fire team be minimized (simplicity) suggests excluding also the teams which contain both automatic rifle and machine gun configurations, (alternatives 4-5, 5-5, 6-5, 6-8 and 6-9). If it is also considered that the requirements of leadership are such that the fire team leader cannot also be an assistant or automatic rifleman, we may also exclude alternatives 4-4, 4-6, 6-7 and

6-10. We are now left with the twelve fire teams organizations shown in Table II. Thus we have reduced the problem to an examination of first the weapon mix (a choice between the automatic rifle and light machine gun) and then a choice among six fire team organizations (see Table II).

It was also decided that because of control problems the more complex six-man fire teams were of less interest than the three, four - and five - man teams. It was decided that trends established with the smaller teams should indicate whether excursions to six-man teams were necessary in the field testing portion of the investigation.

The requirement that the fire team be able to operate effectively as an entity under sustained stress reduces the attractiveness of the smaller fire teams. Fatigue seriously degrades effectiveness; the basic unit should be organized so as to permit continuous watch to be maintained with a minimum of fatigue. If it is deemed desirable to continue the practice of placing two men in a fox hole, the fire team should contain an even number of men.

Based on the above discussion, it seemed reasonable to determine first the weapons mix, that is, to choose between the automatic rifle and the light machine gun configurations. This was done with squad tests using the four-man fire teams. Once the choice of weapons was made, examinations of other fire team sizes was conducted.

Measures of Effectiveness

No single measure of effectiveness can be used to establish the performance of a small arms weapon system in diverse areas such as accuracy, concentration and distribution of fire, handling characteristics, reliability and sustainability. Nor is it clear that combat effectiveness can be measured by any combination of the target effects and ammunition

TABLE II

LIKELY FIRE TEAM ORGANIZATIONS

3 Men Alternative #	3 Men Mix	4 Men Alternative #	4 Men Mix	5 Men Alternative #	5 Men Mix	6 Men Alternative #	6 Men Mix
3-2	RRA	4-2	RRRA	5-2	RRRRA	6-2	RRRRRA
3-3	RRM	4-3	RRRM	5-3	RRRRM	6-3	RRRRRM
				5-4	RRRAA	6-4	RRRRAA
				5-5	RRRMM	6-5	RRRRMM

considerations listed above. The measures of target effectiveness which were considered for the Stoner Battalion Troop Tests and what each attempts to show are as follows (the order is not significant).

a. Total rounds fired - a measure of tactical rate of fire (volume of fire) for the standard scenarios, which reflects suppressive fire. A high tactical rate of fire is desirable if it does not affect sustainability.

b. Hits - the total number of hits on all targets.

c. Hits/Targets hit - a measure of multiple hits. Multiple hits will increase the probability of a casualty for the target, however, multiple hits will decrease total number of casualties.

d. Percent of targets hit - a measure of target acquisition and distribution of fire. It also adjusts targets hit for any differences of targets presented to the various fire teams.

e. Hits/100 rounds fired - a measure of accuracy (efficiency). This measure must be considered with "hits" since the need for accuracy decreases as the tactical rate of fire increases.

f. CET - target exposure time until first hit (CET is the cummulative exposure time).

These measures of target effects reflect the ability of shooter and weapon, in combination, to respond quickly and effectively to a changing threat. Different measures emphasize accuracy (efficiency), effective rate of fire, weapon handling characteristics, individual mobility, fire distribution, volume of fire and suppression. It is clearly not possible to separate these factors.

It was not possible to measure adequately all of these factors. In addition to the limitations in the measures themselves, limitations in

the ranges and instrumentation combined with inevitable characteristics of troop tests to cause difficulties.

The cumulative exposure time measure was not used as the instrumentation at Camp Lejeune did not permit us to accurately get the time until first hit on a target. There were variations in target exposure time and the number of targets presented was not always constant due to difficulties with the operating mechanisms on certain targets.

Experimental Design and Results

Squad level tests were conducted using the four man fire teams, each with one automatic weapon. One half of the squads were equipped with light machine guns as the automatic weapon and the other half of the squads with the automatic rifle. A Latin Squares test was used in order to isolate or cancel effects of environment and training. Twelve squads fired four courses which were designed to provide a wide variety of tactical environments. Each squad was tested in four situations: day offense, day defense, night offense and night defense.

The results of this test did not provide a basis for an automatic weapon selection except in the difference in malfunction rate. The malfunction rate of the machine gun was much higher than the automatic rifle. Thus the decision was made to conduct the fire team tests using the automatic rifle rather than the light machine gun.

A Latin Square design was used for the fire team tests. Each fire team was to fire in the four tactical situations mentioned above. One of the surprising outcomes of these tests was the relative effectiveness of the three-man fire team. A three man fire team might be considered as a four man fire team which has sustained a casualty. Thus the ability of the four-man team to produce target effects is not proportionately degraded by a single casualty. Since the three-man team appeared attractive, it was appropriate to ask what influence a casualty would have on its ability to produce target effects. This question led to the scheduling of tests with a

two-man fire team with one automatic rifle.

The two-man fire team hit a substantially lower percent of the targets than did the three-man teams. This decrease in number of targets hit might indicate that the number of targets presented was not large enough to adequately discriminate among the three, four and five-man fire teams. The number of targets presented at a given time should be great enough so that the largest fire team being tested would have difficulty engaging all of them.

In terms of coverage of the objective (percent of targets hit) the five-man team with one automatic rifle produced only a slight increase in performance over the four-man team. The five-man fire team with two automatic rifles achieved a better distribution of fire but at the cost of a sharp decrease in accuracy.

The relative effectiveness of the four-man fire team was greatest during the more difficult situations, i. e. night offense and night defense. The percent of targets hit was almost a linear function of fire-team size for day situations, whereas the percent of targets hit for night situations peaked at the four-man fire team level.

The results of the test indicate that increasing the fire team size to five men with one or two automatic rifles produced little improvement in target effects; while the potential problems to be encountered by reducing the fire team to three mean are substantial.

FIELD EVALUATIONS OF SMALL ARMS WEAPONS FAMILIES AND SMALL INFANTRY UNITS

Mr. George M. Gividen

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Cognizant Agency: U. S. Army Combat Developments Command

The United States Combat Developments Command Experimentation Command (CDCEC) is the Army's "field laboratory" for combat developments. It is here that various possible combinations of soldier-doctrine-small arms, and infantry unit organization are brought together in a simulation of combat and it is this simulation of combat that we refer to as a military field experiment. From the experiment are obtained data needed to assist in determining what combinations of small arms weapons, personnel, doctrine and units will prove most effective on future battlefields.

Now obviously we can't duplicate the entire battlefield of the future in a military field experiment but, on the other hand, we have to do the best that we can. And we normally do this by attempting to recreate a representative miniature slice of a battlefield. A representative "enemy" threat is designed and placed in a typical combat situation or series of situations on the ground. Then a proposed system consisting of soldiers - doctrine - materiel and organization, is pitted against the threat. Often using sophisticated electromechanical instrumentation CDCEC obtains data from each encounter during the experimentation trial. In collecting this data we conduct as many trials as possible within the limits of the time, money and personnel we have available. And in so doing we attempt to insure that the data collected is as reliable and valid as possible. Data from the field experiment, combined with other data, give a composite picture for analysis.

Our objective is to displace, wherever possible, opinion with fact in matters involving how the infantry soldier of the future shall fight, with what weapons he will be equipped, and how he will be organized. We want to know how big the platoon should be and how many squads shall compose it. We want to know if there should be three fire teams or basic infantry elements in a squad, or should the squad itself be the basic element. Should this basic infantry element be 3 men or 4 men or 7 men? Should each squad or element of the platoon be equipped homogeneously or should three squads carry rifles with all of the other weapons concentrated in a weapons squad. Should each member of the rifle squad carry a dual purpose weapon such as the M16/XM148 combination, or should some of the soldiers in a basic infantry element carry only rifles and other soldiers carry only grenade launchers? Should the leader have the only radio or should every infantryman have one, and if so, should these be two way radios or one way radios. These are but a few of the questions about small arms and infantry units that we are trying to help answer at CDCEC. Although our interest today is only with small arms and small infantry units, I must point out, as most of you know, that CDCEC is also involved quite extensively with the other combat arms branches of the service as well. As such, we are also in the business of conducting armor, artillery and aviation experiments.

Our two most recent large scale infantry efforts have been the Small Arms Weapons Systems Experiment, more popularly known as the SAWS study, and the Infantry Rifle Unit Study for time frame 1975 and this one is usually called IRUS-75.

The first of these efforts, SAWS, was run in 1965 and the early spring of 1966. Here we compared 10 different type rifle squads each armed with different mixes of small arms. The weapons that we looked at here were 5.56mm Colt M16 rifles and automatic rifles, the 5.56 Stoner rifle, automatic rifle and machinegun, the 7.62mm M14 rifle, M14E2 automatic rifle and M60 machinegun, and the Soviet AK47 rifle. We also conducted limited firings with the Soviet DPM and RPD machineguns, which are found today in Vietnam. The experiment consisted of firing the various infantry rifle squads in 6 different simulated combat situations, each designed to test different mechanisms of small arms fire in infantry combat. The units were fired in the attack and defense, and in a support role. They were fired at day and at night. The targets they fired at were at ranges of 20 meters to 700 meters and were concealed, partially concealed and completely exposed. Some were in groups, some were located by themselves. Some were "head and shoulders" and some were standing. The men fired from foxholes and from quickfire positions, stationary and moving. Some situations required carefully aimed point fire while others required area fire. The targets were pop up targets that remained exposed for relatively realistic time periods. Associated with the targets were rifle, automatic rifle and machinegun simulators. The target arrays were, as a result of a threat analysis, laid out to resemble the deployment of Soviet or Chinese units in similar situations. When a target was hit it fell and did not rise again. These hits were transmitted to a computer and put onto magnetic tape as a function of the time at which they occurred. Additionally, near misses that passed within 2 meters of the target center and ammunition expenditure were automatically recorded as a function of time. We, therefore, knew not just how many targets had been hit, but exactly when the hits had occurred, how much ammunition had been used to get each hit, and how many near misses there were for each target. In theory, the longer the enemy target was up and its weapon simulator firing, the more enemy fire the friendly unit was subjected to. Thus, the important thing to consider here was not just how many targets a weapons mix was able to hit, but how quickly they could hit them. In this respect the measure of effectiveness we used to determine how effective a weapons mix was in any given situation was the total of target exposure times for all targets in that particular situation and the unit which was able to come up with the <u>least</u> cumulative exposure time for any target array was the best unit in target effects on that array since it had received the least amount of return enemy fire. Additionally, as an indication of the suppression ability of a unit we considered how many near misses within 2 meters of the target were achieved.

We then considered how much ammunition was required to secure these target effects. The unit which secured the greatest target effects per pound of ammunition used was the most efficient in ammunition consumption. But this is not the whole story either, because in order to determine the effectiveness of any weapons system or small infantry unit, we must consider not only target effects and the amount of ammunition required to achieve them, but also the

amount of ammunition available to a weapons mix within a constant systems weight, a weight that remains constant for units of the same size. Just as the weight of bombs that can be put into the belly of any given airplane is limited, so is the weight of the weapons and ammunition that go onto the back of an infantryman.

For example, current Army doctrine prescribes that the total basic weapons system weight that the rifleman should carry is approximately 17 pounds. Since the infantryman is weight constrained, those soldiers and units that carry the heaviest weapons carry the least ammunition and consequently they have the least to fire. Conversely, dismounted units with the lightest total weight of weapons can carry the most ammunition. All other things being equal, an infantry squad that can carry twice as much as another squad armed with different weapons needs to be resupplied with ammunition only half as often and can sustain its target effects twice as long. Therefore, in evaluating the effectiveness of a small infantry unit we must consider the ability of the unit to hit targets, the ability of the unit to suppress the enemy, the amount of ammunition expended to achieve its hits and suppressive effects, the timeliness of its target effects, how long it can sustain its target effects, and how often it needs to be resupplied with ammunition. In terms of target effects the weight of the individual round of ammunition is important too. And this is the bonus advantage of the 5.56mm weapons, and the SPIW. For not only is there an advantage in the fact that the 5.56 bullet weighs 1/2 as much as the 7.62, but this permits, in general, a lighter weapon. We see this in Vietnam today where the M14 rifle within its 17 pound basic load can have only <u>100</u> rounds of ammunition while the Colt M16 within the same 17 pound load has <u>300</u> rounds. Another example is the Stoner machinegun in contrast to the heavier M60. In this case, the spare barrel kit of the M60 weighs more than the whole Stoner machinegun. And, here, within the same weapons system weight the M60 crew can carry only 800 rounds of ammunition as contrasted to 2300 rounds for the Stoner, and that's quite an advantage. In this respect, the Stoner units might choose to carry only 1600 rounds which is still twice as many as the M60, and trade off the rest of their lighter weapon/ammunition advantage by carrying a lighter load. And this, of course, would normally result in greater mobility.

The reliability of weapons to include malfunction and maintenance problems is also an important factor. In a field experiment the results of the experiment in terms of target effects and ammunition expenditure reflect the malfunction rate. For example, the target effects of the Stoner machinegun in repeated field experiments have not been as high as might be expected. On the other hand, the weapon-ammunition system has consistently had more malfunctions than any other system we've tested. In like manner, CDC and Congressional reports, supported by CDCEC results, point out the high rate of malfunctions of the M16 rifle/ball powder ammunition system when compared with the M14. Yet, even with the malfunctions, the performance of the M16 has proven to be superior to the M14 in most situations.

The results of the CDCEC SAWS field experiment lent a new dimension to the analysis of small arms weapons systems by its consideration of the total system to include the men and the units who would actually be using the weapons, relatively realistic target arrays, the collection and analysis of data as a function of time, and due considerations of the fact that the infantryman is severely weight limited.

The results of the SAWS study are now quite well known to most of you. For that reason I'm not going to go into any detail other than to summarize quite briefly our findings. The rank order of these weapons mixes as determined by the CDCEC experiment is shown on this slide which has been reproduced from the official CDC report. The report is on file at DDC and is available to those of you who have not seen it already. It is classified For Official Use Only. I would have you note that in target effects the Stoner and M16 units were approximately equivalent. However, the advantage of having light weapons and being able to carry significantly greater amounts of ammunition give the Colt M16 units a substantial advantage, with the result that it was concluded that units equipped with M16 weapons were superior to all other units in overall effectiveness. Now the particular mixes listed on this slide were as follows from top to bottom in rank order:

1. 7 Colt rifles, 2 Colt ARs
2. 9 Colt rifles
3. 7 Stoner rifles, 2 Stoner ARs
4. 9 Stoner rifles
5. 7 Stoner rifles, 2 Stoner machineguns
6. 9 M14 rifles
7. 7 M14s and 2 M14E2 automatic rifles
8. 2 M60 machineguns and 5 rifles. This was a 9 man squad but the weight of the weapon and its ammunition required that 2 men be assigned to each gun - one to fire and one to carry ammunition.
9. 9 Soviet AK47 rifles.
10. 9 M14E2 automatic rifles

Don't be deceived by the low score of the AK47s however. We don't feel that this is a valid indication of the weapon's ability. As contrasted to new individual weapons used by the other mixes, we only had 11 AK47s which were shared by all AK47 squads, so the wear on these weapons during the experiment was much greater than for the U. S. weapons. Also, these were weapons captured in Vietnam and we have no idea of how many rounds had been fired through them before we got them. We actually used 9 weapons for all of the firers and had to cannibalize the other two for spare parts. Furthermore, the AK47 is primarily designed as a submachinegun type weapon for close in firing. The sights are close together and the barrel is short.

Were we to weight our experimental results in accordance with the frequency of ranges as they occur in actual combat, the AK47 would have done better. I would also mention too, that, in spite of its poor target effects scores, the CDC report concludes that it is a more reliable weapon than any of the current 5.56 or 7.62 U.S. weapons.

Last is the M14E2 mix and this was a mix where every man was equipped with an M14E2 automatic rifle. Not only did the mix finish last in target effects, but it was also the worst mix in sustainability. The heavy weapon permitted the firer to carry only 80 rounds of ammunition within a 17 pound basic load as opposed to 100 for the M14, 180 for the Stoner and 300 for the Colt.

In the Infantry Rifle Unit Study (IRUS) similar ranges and procedures have been used to attempt to evaluate the combat effectiveness of different infantry units of varying sizes and with varying weapons mixes. We have investigated the relative fire effectiveness against identical threats of 1, 3, 5, 7, 9 and 11 man units equipped with rifles. We have varied the proportion of grenade launchers from 0 in a unit to 100%.

We have compared the effectiveness of different units in a support role and recently finished a report comparing the relative effectiveness of support units armed with automatic grenade launchers, M60 machineguns, Stoner machineguns, and nothing but M16 rifles and XM148 grenade launchers. We have looked into the improvement in target effects offered by passive night vision devices and the decrements resulting from the wearing of toxic protective gear. Controllability of various units and the effect of different mixes of radios on the fire effectiveness of a unit have been examined on these ranges.

But live fire evaluations are not the only way we examine these infantry systems. We must get into details that, in some cases, can be better examined in two sided non-live fire situations. For this purpose we have designed two field experimentation courses, both of which are partly instrumented. Both of these courses use live aggressor forces rather than stationary targets. One of these courses is 1800 meters long and makes extensive use of electronic instrumentation, such as round count devices which emit microwave signals each time a soldier's weapon fires a round, and remote wrist units which are used by observers to input personnel exposure times to the on line computers. Experimental data is recorded on magnetic tape and used after the exercise in the evaluations for purposes of estimating the relative number of casualties that would have been sustained by the different units being evaluated. However, these instrumented measurements aren't by any means all we're looking at, for a far greater quantity of manual data, rather than instrumented, is collected and used in the evaluations. For example, controllers following the units record manually the time consumed by each type unit in traversing the various sections of the course, the amount of dispersion among members of the units, and number of orders that the unit leaders had to give in order to maintain proper control of the unit. Additionally, the relative numbers of tactical errors which the observers determine to have been made by each unit are recorded and considered in the analyses. For example, a tactical error might be recorded when one squad moved into a position which masked the fire of another friendly squad.

The other non-live fire experimentation course is considerably longer - it covers a total distance of 18.5 miles which includes as one phase of the course the entire 1800 meter shorter course just discussed. It takes each unit approximately 72 hours to "fight" its way through this course. The concept is patterned after the famous 72 hour course that has been used since 1952 by the Army's Ranger Training School at Dahlonega, Georgia. Units going through this test engage in a road march, a day attack, a night attack, a night withdrawal, the setting up of a holding position, reconnaissance patrols, passing through mine fields and an ambush situation. The units, during the last phase of the 3 day problem, move into a live fire attack situation on the ranges discussed earlier when we were talking about "live fire" fire effectiveness comparisons.

At present we have been limited to the evaluation of units platoon size or smaller. But in the near future we hope to be able to expand our work with small arms systems and infantry units to the point where we can handle company size units. And we anticipate further instrumentation developments too. Next month CDCEC will receive a prototype of a new position location system - the range measuring system 2 (RMS-2 for short). Under control of the central computer, the RMS-2 can be automatically programmed to identify and measure range of each maneuvering infantry element 1800 times per second with an accuracy of 3 meters. Range data is used to compute the position of each unit. The related computer also transmits command messages and receives status messages from maneuvering elements. At this time we're also working on specifications for a second generation personnel target subsystem where vertically rising targets are operated by radio control from the central computer.

CDCEC provides the laboratory for comparative field evaluations of small arms families and new ideas in small infantry units. Our experiments are not completely combat realistic - they obviously cannot be. For example, we can never duplicate the fear of combat nor the effects of this fear. But we have tried to make each experiment as combat realistic as possible, and we do know that we have been able to duplicate at least some parts of the battlefield situation. For objective quantitative evaluation purposes, CDCEC's field experiments are the closest thing to combat except for combat itself. In closing, I must mention that only a small part of CDCEC's evaluation of a weapons system (and, within this context, I'm referring to small infantry units as weapon systems) consists of the actual experiment on the field.

There is a tremendous amount of work that goes into systems analysis before we ever go to the field. And if we don't know the system as well as possible we can't properly design an experiment. Then, after the experiment is over we have to analyze and evaluate the data and draw conclusions and make recommendations. And the result of all of this is not that CDCEC provides all of the answers to any questions in the small arms or infantry area, but we do provide data and associated analyses to assist the systems analyst on the DA and DoD level in making a better decision than he would otherwise be able to do.

Thank you.

SYSTEMS ANALYSIS FACES EVERYMAN

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It is a great pleasure to speak to all of you systems analysts tonight. Some of you may be mentally objecting to the title of Systems Analyst, but I have it on good authority - from the new book of Van Court Hare, Jr. of Columbia University. To estimate the number of "persons engaged in systems analysis and related activities" Hare uses the 1966 membership lists of certain professional societies plus "various special groups in industry and government" and arrives at 300 thousand. (That is, by the way, about the same number as there are designers and draftsmen, or physicians and surgeons, and somewhat more than the number of lawyers and judges, or clergymen, or college professors, instructors and administrators, or social, welfare and recreational workers). Since Hare gives the impression he may well have used the attendance roster at this symposium for one of his sources, and since he includes such professional societies as ORSA, TIMS, IEEE and ACM, as well as the Systems and Procedures Association and the General Systems Society, I think it only reasonable to address all of you as systems analysts. In fact, I suspect that in Hare's count some of you are several times a systems analyst.

While I plan to talk tonight about systems analysis, I won't, however, be describing specific systems analysis techniques, nor will I particularly dwell on specific large, important, and interesting systems. Rather, I'd like to remind you of the broadening impact of the systems approach upon all phases of American life and to describe some of the areas in which it seems that systems concepts will be important in the future.

I think we can be rather relaxed about the use of terms tonight, so I shall not distinguish between systems analysis and other features of systems study, such as systems definition, systems treatment, systems design, and so forth. Tonight we will be examining only the more general feature of the systems approach; the consideration of a collection of elements and their relationships as assembled for a specific purpose.

I have chosen the title "Systems Analysis Faces Everyman". Everyman was the protagonist of a 15th or 16th century English morality play, written by some forgotten priest of the church. Everyman, who is on the way to "that country from which no traveler returns" (Death), meets such personifications as Fellowship, Goods, Good Deeds, Knowledge, Strength, and so forth. The point of the play is the distinction between those qualities which can and those which cannot accompany and sustain Everyman on his journey. Now I want to take a 20th century look at the confrontation with Systems Analysis which faces Everyman. (I might mention that I have something of an obsession about acronyms -- for example we are developing a "total" information and decision system which we call the "Future Integrated Control System" -- that one comes out "FICS", and we pronounce it "fix", which we thought rather appropriate. Similarly, for this eminent and distinguished audience I carefully chose a topic which is, at least acronymically, "SAFE".)

Well, who am I to talk about systems? Perhaps I can play Everyman - certainly I'm not one who set out to become an expert on systems. In fact there was a very gradual process of realizing that systems considerations were an important part of my professional role. I was rather narrowly trained as a mathematical statistician and, few years ago, was employed by C-E-I-R, Inc., working under contract to Dugway Proving Ground. Our original concept was that we were providing research and consulting services in the application of statistics. Over a period of time we grew aware that what we were really doing was contributing to the testing and evaluation of systems and that the consideration of system performance was crucial, while the nature of the methods of data manipulation was of a lower order of importance. I believe our contributions to the effectiveness of the Dugway mission then increased correspondingly.

At Hallmark Cards, Operations Research is one of the departments for which I am responsible. In our early days we tended to be very conscious of the techniques of operations research so widely applied and so well documented in journals and books. Most of our new young analysts, upon arrival, have a similar mental set. But the department and its members have become increasingly aware that our most important function is the analysis of Hallmark's systems for doing business and the design of better systems. And this trend seems to be a very general one in the business community.

Adrian McDonough of the Wharton School says, as the first of a set of propositions concerning information management, "A business is a collection of problems to be solved". (At Hallmark our Marketing people would prefer to say "challenges" rather than "problems". In fact, they like the word "opportunities" even better. Of course it then becomes rather difficult to speak of an insurmountable opportunity.)

I think you may be interested in the complete set of McDonough's propositions. I have found mental stimulation in them. They are: (1) A business is a collection of problems to be solved. (2) Organization is the process of assigning problems to the most qualified individual (or group). (3) The most qualified person is the one who will need the least information services to make the best decisions. (4) Information is the measure of the value (worth) of a message to a decision maker in a specific situation. (5) The purpose of [an information] system is to carry information to decision makers. (6) Any system is a logical configuration of the significant elements in a selected problem area.

I am not going to develop these propositions further tonight - McDonough does that job in his book. However I think that the fact that this is the kind of reading material currently favored by many business managers signifies a real change in direction. McDonough and others whose audiences include the business managers of today and tomorrow are preaching, explicitly and by example, the benefits of the systems approach.

Are businessmen listening? I feel sure that they are. The existence of shelves full of books on systems and the vast number of articles devoted to systems in business periodicals do not of themselves prove that anyone is paying attention. Advertisers, on the other hand, are well known to pay close attention to the question of who is listening. It seems increasingly difficult to sell to a businessman without at least hinting that the product or service involved has been specifically developed from a systems point of

view. For example, in the current (May) edition of "Dun's Review" I counted 25 of the display advertisements using the word "system" somewhere in the message. Of course some of these allusions were trivial, but a number refer to filing systems, material handling systems, packaging systems, automated business systems, payroll and accounting records systems, control systems, etc. One firm, S. I. Handling Systems, uses the motto "Systems is our surname" in advertising its automated material handling systems.

Of course the various sectors of business have experienced the systems approach to different extents. In fact the progress of the various sectors in this respect seems to be correlated with their performance with respect to productivity. If we take the relative growth rates of "value added" versus payroll for the first half of this decade we find that mining (including mineral extraction generally, e.g., crude oil production) has shown a productivity increase of approximately 20%, obtaining nearly 20% increase in production with slightly lower expenditures in payroll. It is, in my opinion, no coincidence that firms in the mining industry have been among the first to view the total operation as an integrated system and to develop elements of production which are in themselves efficient and which relate to one another in the best way for attainment of the objective - the extraction of minerals from the earth.

Three other sectors, Durables Manufacturing, Non-durables Manufacturing and Transportation and Utilities all experienced about a 10% gain in productivity from 1960 to 1965. These sectors have been typified by the development of large scale systems for the accomplishment of some of the functions of the firm. For example, computerized accounting and payroll systems became the rule. Inventory control systems are widely employed. Production control systems are prevalent in some industries. In transportation we have found such expressions of the systems approach as the railroad's piggyback freight operations and the airlines passenger reservations systems being developed and exploited between 1960 and 1965.

However, the rate of advance differs widely among industries within the manufacturing sector. Of the 20 major industries recognized by two-digit classifications in the Government's Standard Industrial Classification, the Petroleum and Coal Products industry has most completely embraced the systems approach. In refining, we now find almost totally automated production systems as the dominant feature of the industry. Small wonder then that productivity per payroll dollar increased by nearly 50% from 1958 to 1963 and another 30% by 1966! Meanwhile, Rubber and Plastics Manufacturing, Leather and Leather Products, and Stone, Clay and Glass Products have shown virtually no productivity increases. The Electrical Machinery industry, which has contributed heavily to advanced systems elsewhere, actually showed a slight decline in productivity between 1958 and 1963. At this end of the scale we find industries in which the "total systems" approach to production has yet to be proven feasible.

In passing, I might note that the Greeting Card industry, a subclassification of the printing and publishing industry, also experienced a slight decline in productivity from 1958 to 1966. I think our difficulty may be typical of those of other lagging industries. Hallmark, for example, produces nearly 15 thousand distinct products each year, in quantities which vary a hundred-fold. We have nearly 40 thousand retailers as our immediate

customers. The number of orders filled per year runs into nine figures. The design and creative processes must be individualized and distinctive in order to maintain sales appeal. The manufacturing processes differ greatly from product to product and are accomplished in essentially a job-shop manner. The goal of a total system development at Hallmark is thus a difficult one and the economies involved have been marginal until very recently. But Hallmark is the largest firm in the industry and best able to employ scale economies and to allocate resources toward such a development. We now expect to have a total information and control system functioning within five years, with some of the components going on line earlier, but it will be much longer before the total systems approach becomes standard for our industry.

Except for Mining, Manufacturing, and Transportation and Utilities, there are no other sectors of business which have shown productivity increases in the years just prior to 1965. These relatively stagnant sectors include Construction; Finance, Insurance and Real Estate; Services, and Wholesale and Retail Trade. The last sector has experienced a slight decline in productivity per payroll dollar. I think that great advances are yet to be made by application of systems technology within these sectors. In fact evidences are already at hand in the Construction sector -- but construction has also been hit by the greatest increases in unit labor costs. Since 1965, banking and other areas of the Finance, Insurance and Real Estate sector have moved rapidly, aided by second and third generation computer systems, into the development of total business systems. Automated conveyance of money and credits is an obvious application of the systems approach and it seems to have been only the traditional conservatism of this sector which has delayed this development to the present time.

In trade, too, there are obvious systems developments. The development of the supermarket concept, beginning in groceries a generation ago and more recently in softgoods and other products, represents to me a systems approach to retail merchandising. Current extensions of the system include more effective means for transporting the customer to the marketplace and for transporting the goods from check-out to the customer's automobile. Automated or semi-automated processes for ordering, inventorying, and stocking appear promising.

Outside the food retailers, there are some other areas of progress. Some of the giant merchandising firms such as Sears, Wards, and Penny's are also advancing toward a total systems goal. "Variety" merchants, too, are moving toward new retailing systems exemplified by the Woolco and K-Mart type of operation.

So much for systems and Everyman as businessman. It appears almost inevitable that the systems approach will have a much greater impact on his work in the years to come. But what of Everyman as consumer? Here, too, I think, there has already been substantial change with much more to come because of the systems approach. Let's look at the usual categories of personal economic consumption.

First on the list in terms of volume of expenditures is the category of Food, Beverages and Tobacco. We may note in this area a significant early development in systems designed to serve motorists - the drive-in

concept. Recognition of a substantial market for convenient and economical food service to our automobiling millions has led to a multi-billion dollar business.

The area of home food services, however, seems to have been relatively untouched by the systems approach. Appliances for food preparation proliferate and become ever more complicated and versatile, but the concept of the home food preparation center as a system has yet to be exploited. I find this an intriguing possibility.

One interesting marketing system concept in this area is the "food plan". In Kansas City, for example, we now have seven firms offering this service, which consists of filling monthly or weekly orders at the warehouse, assembling and delivering the orders directly to the home (in some cases placing the items on the cupboard shelves or in the refrigerator) and providing a monthly billing, all at a cost competitive with more traditional food distribution.

Housing is the second major category of personal consumption expenditures. We have seen recent examples of what might be termed housing systems, among which I'll cite merely Habitat '67, developed in conjunction with Expo '67 at Montreal. For those interested in this subject, I recommend the book "Environment and Man, the Next 50 Years", edited by William R. Ewald, Jr.

Household Operations, including furniture equipment and supplies, all utilities and domestic services is third in consumer expenditures. The most immediate area of systems development in this category appears to be in the telephone utility. Direct distance dialing, for example, represented a major systems achievement, perhaps unparalleled in the area of consumer systems. We are promised a future filled with video phones and other systems innovations, hopefully more significant than the Princess phone. As I will mention later, I believe that many other types of consumer-oriented systems will rely on the telephone line or its equivalent for communication with the individual household.

Personal Transportation is an area in which the systems approach has already begun to pay some dividends, notably in California's Bay Area Rapid Transit System. It remains to be seen, however, whether other public transportation systems can be evolved in time to meet the growing need. The automobile may yet overwhelm us in acres and acres of parking lots (including those designated as thoroughfares) and lead to a decentralization of population which will make public transportation systems even more difficult to develop. However, it would be remiss to speak of transportation systems without acknowledging the inter-state highway system, which fits most definitions of systems; that is, it was designed as a system comprised of many elements for a specific purpose.

We may also note the success of a less important kind of system involving our personal automobiles, namely the car-wash system. The future of transportation offers much challenge to the systems approach and many concepts could be considered. How about, for example, lifting the idea of "piggyback" rail transportation and applying it to families and their automobiles for long distance travel? Could that put railroads back in the passenger business? I believe the Seaboard Coast Lines is currently

investigating such a system; operating systems may be found in France and elsewhere in Europe.

Perhaps Clothing, Accessories and Jewelry will never be a fruitful field for consumer systems. However, we are currently seeing imaginative uses of materials in this area, although a casual glance at hemlines suggests that some of these materials may be in short supply! With the growing emphasis on technological developments in the clothing area there may in fact be opportunity for the development of clothing systems. And certainly the current methods for clothing maintenance might well be improved through systems study. The commercial cleaning and pressing trade and self-service industry might both profit from systems analysis. And, in spite of the improvement in the individual devices, the home clothing maintenance operation, as a system, has advanced very little.

The greatest systems impact on the individual consumer over the next few years may well lie in the area of Personal Business. I think it is a conservative projection to believe that we will soon bank by wire rather than by mail or from our automobiles. It appears certain that our funds will be dispersed from our banks to our creditors electronically, having travelled from our employers to the bank in a similar manner. (I can visualize a certain problem in trying to catch up financially to the point where I can keep my personal accounts in the black without the "float" in the present financial system. I understand, however, that banking systems analysts are even prepared to program "float" into the system in order to induce customers to participate.)

Just as personal business will be transacted by wire, so also may private education and research facilities in the home be linked to libraries or other repositories of information. It seems plausible to couple the home entertainment center to such a system as well. Thus a coaxial cable may well become an umbilical cord to the home of the future, carrying communications, education, business transactions and entertainment to the family. Such a system is technologically feasible today and should be economically feasible in a very short time. It remains to be seen whether business enterprise will undertake such a mammoth task. Unfortunately, those firms which are currently best equipped for such a job are sensitive about encroaching into new fields of consumer service from entrenched monopoly positions. Thus political and social issues may well be of paramount importance in the realization of such systems.

In summary, I see the systems approach more and more affecting Everyman at home as well as on the job. It is my belief that systems analysis will walk with Everyman and be rewarding company in the journey.

I only wonder if 300 thousand of us is enough.

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ECONOMIC ANALYSIS OF INFANTRY FIREPOWER

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Introductory

We want to discuss some of the factors that are important in thinking about firepower with regards to the general purpose forces. Our interest will be centered on the economics of killing targets in land warfare, ignoring those other principles of war such as maneuver, concentration, communications, surprise, intelligence, etc. A general treatment of firepower and cost is beyond the scope of this memo. In fact, an analysis of army firepower with today's methods is almost impossible of accomplishment. To do a first order analysis of firepower it is necessary to scale down the problem to one of manageable proportions. Accordingly we restrict firepower to infantry weapons and small military operations, relying strictly on elementary reasoning in formulating the essential components of the problem. Although limited in scope, this permits one, under drastic simplifications, to approach the solution to the problem of resource allocation and casualty production of a small tactical unit. Basically, our purpose is to determine the price of killing ground targets with infantry weapons. In particular, we desire to examine the effectiveness of small caliber ammunition against personnel and to estimate the cost of inflicting casualties.

Problem Description

The essence of the economic-firepower problem is characterized as follows:

Consider a combat commander in the field who has at his disposal a fire support unit with a limited supply of ammunition and an enemy whom he can bring under attack with this resource. How does the commander decide on the allocation of his ammunition resource? What target should the resources be applied against and to what extent? From his intelligence gathering system, the tactical commander estimates the nature of the enemy he faces and has a knowledge of what his weapons can achieve against that target. Admittedly both pieces of information regarding the enemy and weapon capability are imperfect. Nonetheless, he also knows that it is foolish to waste ammunition in overkilling a target. When the target is brought under fire at what point should the firing sequence be terminated.

The answer to the question regarding the decision to terminate the attack on a given target can be obtained to first approximation by considering the concept of supply and demand. It may, at first, appear odd to talk about supply and demand with respect to producing casualties in combat on

the battlefield. The attacker or defender seeks to break the opposing force's will to resist by maximizing casualties. It is assumed that the principal objective of armament by a tactical unit is the creation of damage to the enemy or the reduction of his capability. Unlike the strategic offensive forces, the possession of arms by tactical unit is not for deterrent purposes, but for offense or defense. The primary output of arms is casualties. We desire to defeat the enemy, but to what degree and to what cost in resources or money. Weapons and munitions are scarce commodities, and their possession and expenditure represent money. If the target is an infantry company, usually about 30% casualties is sufficient to cause resistance breakdown. Against a given target the attacker or defender has, under certain conditions, control over both supply and demand of casualties; e.g., he cannot extract more casualties than men in the target area and he cannot fire more ammunition than he has available. The solution of the problem of when to terminate the attack is expressable in dollars. It is represented by the intersection of supply and demand functions. Figure 1 contains typical supply and demand kill functions for an attacker or defender.

Casualty Production Function

Now we turn our attention to a simple case of a tactical operation to illustrate a method of obtaining the casualty supply function of one of its participants. What is desired is the magnitude of the cost of producing casualties in a target area containing men. The best way to describe the problem is to take a numerical example which we develop from a simplified tactical situation involving a small caliber attack on a passive infantry company. Consider an infantry company receiving fire from the air, say from helicopter armament or from machine guns carried by fixed wing aricraft.

The situation is summarized as follows:

Imagine a simplified tactical condition in which an infantry company is under small arms attack and passively submits to it. For simplicity, assume the infantry company is being fired upon from the air so that terrain cover and shielding has no effect on the incoming fire. The fire on the target is coming vertically downward; hence, each soldier in the target area is fully and equally exposed to the field of fire. Suppose the infantry company contained 160 men scattered over a one square hectometer area. Target characteristics are given by homogeneous elements having uniform vulnerability to the fire, with no replacements permitted during the assault.

Suppose that n small caliber rounds are fired randomly and scattered with uniform density into the target area containing 160 man infantry company. The gunners of the attacking force are not capable of observing their fire. They cannot transfer fire from one point to another in the target area. The target area is simply sprayed with small caliber bullets. Guns are not aimed individually at a soldier in the infantry company. Under this assumption the probability of hitting and killing a particular man with one round is independent of the probability of hitting him with any other round. For any given soldier in the target area, the chance that a round will hit and kill him depends on his exposed area, his vulnerable area, and the total target area

over which fire is distributed. From a total of n rounds fired into the target, let p_i be the probability that the ith round hits and kills the j^{th} man in the target area over which N_o men are distributed. If n rounds are expended on the target, the probability that the j^{th} man is killed is

$$P_j = 1 - \prod_{i=1}^{n} (1-p_i)$$

Since P_i is constant over the entire firing sequence

$$P_j = 1 - (1-p)^n$$

Further since p is small and n is large, the probability of killing the j^{th} man is

$$P_j \doteq 1 - e^{-np} = 1 - e^{-n\frac{A_m P_c}{A_T}}$$

where A_m is the soldier's exposed area

A_T is the total target area

P_c is the conditional kill probability

The expected number of men killed in the target area is obtained by summing the kill probability of each man over all N_o men in the target area. It is

$$E(N) = \sum_{j=1}^{N_o} P_j$$

Since P_j is constant, the expected number of kills is

$$E(N) = N_o P = N_o (1 - e^{-np}) = N_o (1 - e^{-\frac{A_m P_c}{A_T} n})$$

In order to quantify the expected number of kills it is necessary to assign values to a soldier's exposed area and his vulnerable area. The type of weapon employed against the target is a primary variable and must be specified. Assume the attackers are armed with 5.56mm and 7.62mm weapons using ball ammunition. Let A_m be equal to $.5m^2$ and P_c be equal to .3. We have already assumed the target to be 160 man infantry company confined to a $10^4\ m^2$ area. The following constants, to reiterate, define the target under a small arms air assault.

$A_m = .5m^2$

$A_T = 10^4 m^2$

$P_c = .3$

$N_o = 160$

With these assumed constants, the expected number of men killed was calculated as a function of the number of rounds fired. It is plotted in Figure [illegible]. This [illegible]tion is the casualty production function of the attacker [illegible] weapons and on the target characteristics. It is one [illegible]

Linear Cost Function

The next step in the analysis regards cost. The costs of the inputs or the factor prices of the casualty production function are important. Before a round can be fired, equipment, weapons, ammunition, and communications must be procured, soldiers who man the weapons and handle the ammunition must be fed, quartered, paid, medical services provided, etc. There are fixed, investment, and operating costs. However, for our purposes, let us assume that the cost function depends directly on the number of rounds expended on the target. Suppose cost is given by a linear function. We assume that

$$C = \alpha + \beta n$$

where α is the fixed and investment costs
β is the cost per round

The initial cost at $n = 0$ is C_0. C_0 is a difficult constant to evaluate for any system. For example, the men who operate the weapons and handle the ammunition must be fed, trucks are used in transporting food and ammunition, fuel will be burnt in powering the trucks, etc. These factors, essential to the capability of firing a single round, cost something. They are related to the firing of ammunition but how are their costs imputed to the final product, damage to the enemy? In our example the aerial attackers are armed with 5.56mm and 7.62mm weapons using ball ammunition. These weapons fire the 5.56mm M193 and the 7.62mm M80 ball cartridges. The current price per packaged cartridge in million lot procurement is to the nearest tenth of a cent.

Caliber mm	Type	Cartridge cost cents
5.56	M193 Ball	9.6
7.62	M 80 Ball	8.4

These ammunition cost inputs, easy to identify, are the only ones we will use, neglecting the cost of transportation, storage and handling.

Constrained Maximization

The casualty production function and the cost of ammunition have been defined for our hypothetical example. We are now in a position to combine these two factors. It is required to maximize the expected number of casualties subject to a cost constraint. This is recognized as a constrained output maximization problem, the solution of which is the casualty supply curve. It is stated simply as

maximize $\overline{K} = E(N/N_o) = 1 - e^{-an}$

S.T. $C = \alpha + \beta n$

where $a = \frac{A_m}{A_T}$ pc

N_o is the number of soldiers in the target area

Forming the Lagrangian function

$$Z = N_o (1 - e^{-an}) - \lambda (\alpha + \beta n - C)$$

and differentiating with respect to n and setting to zero.

$$\frac{\partial Z}{\partial n} = a N_o e^{-an} - \beta\lambda = 0$$

The Lagrange multiplier is

$$\lambda = \frac{aN_o}{\beta} e^{-an}$$

Now $$\frac{dC}{dE(N)} = \frac{\beta}{aN_o} e^{an} = \frac{\beta}{a(N_o - E(N))} = \frac{\beta A_T}{A_m P_c (N_o - E(N))}$$

This is the important quantity, the cost per kill. It is the casualty supply curve and illustrates how cost increases as more and more of the target is defeated. It is graphically shown in figure 3. It is cheap for the attackers to take the first casualty in their assault on the passive infantry company. To get the last man in the target area is very expensive. Note that the cost per kill grows rapidly as the target approaches complete destruction. At the other extreme, if $\underline{K}$ takes on values near zero, then dC/dN varies linearly with $\underline{K}$ or when $\underline{K} \rightarrow 0$, $dC/dN \doteq \beta (1+\overline{K})/aN_o$ At $\underline{K} = 0$, $dC/dN = \beta/aN_o$ or at $E(N_o) = 0$, $dC/dN = \beta/aN_o$. The cost per casualty is fairly linear up to about 60 fatalities or up to 1/3 of the total target of 160 men. For ease of showing the dependence of cost per kill on the expected number of kills for the two ball weapons the following tabulation is presented

Expected Kills E(N)	Cost/Kill in Dollars 7.62mm	5.56mm
50	50.9	58.2
100	93.3	106.7
150	560	640

To complete the problem we need to know the demand function. Once this function is know, the intersection of supply and demand functions gives us the answer we want. It tells us the number of enemy casualties desired and the marginal cost of getting these casualties.

Total Cost of Killing Targets

The total cost to destroy a fraction of the target is the integral of the cost per casualty times an infinitesimal casualty. Total cost to kill a given fraction of the target Γ is

$$C(\bar{K}) = C_o + \int_0^{\bar{K}} \frac{\beta}{aN_o}\left(\frac{1}{1-x}\right) dx = C_o + \frac{\beta}{aN_o} \ln\left(\frac{1}{1-\bar{K}}\right) = \alpha + \beta\, n(\bar{K})$$

The total cost curve starts at $C_o + \frac{\beta}{aN_o}$, varies linearly with $\bar{K}$ up to about $\bar{K} = .3$, rises rapidly with increasing fractional kill and then becomes asymptotic to the vertical line $\bar{K} = 1$ or when $E(N) = N_o$. Its variation is shown in figure 4 for the 5.56mm and 7.62mm ball weapons.

This graph pretty much tells the story of how costly it is to kill a large fraction of an infantry company with small arms weaponry even under the extremely idealized conditions used to describe the target. The following table shows the cost of getting various numbers of kills on an infantry company with the two ball weapons for which $C_o = 0$.

Expected Kills E(N)	Cost in Dollars 7.62mm	5.56mm
50	2098	2398
100	5493	6277
150	15526	17745

The model suffers from obvious deficiencies. First and most important, the target is passive. It cannot return fire. The attacking unit is not attrited. Secondly the model is static, independent of time. It does not take into account the number of weapons required, their ammunition load, their firing rates, etc. Third it does not consider a mixture of weapons.

Model Modification

The same method can be used in assessing other infantry weapons such as gun-fired grenades and mortars provided their lethal areas are small in comparison with the total target area over which ground troops are distributed. The assumption of a uniform field of fire must hold. The only perturbation to the method involves the single shot kill probability of the weapon. In the case of a fragmentation weapon, single shot kill probability equals lethal area divided by the total target area. The casualty production function becomes

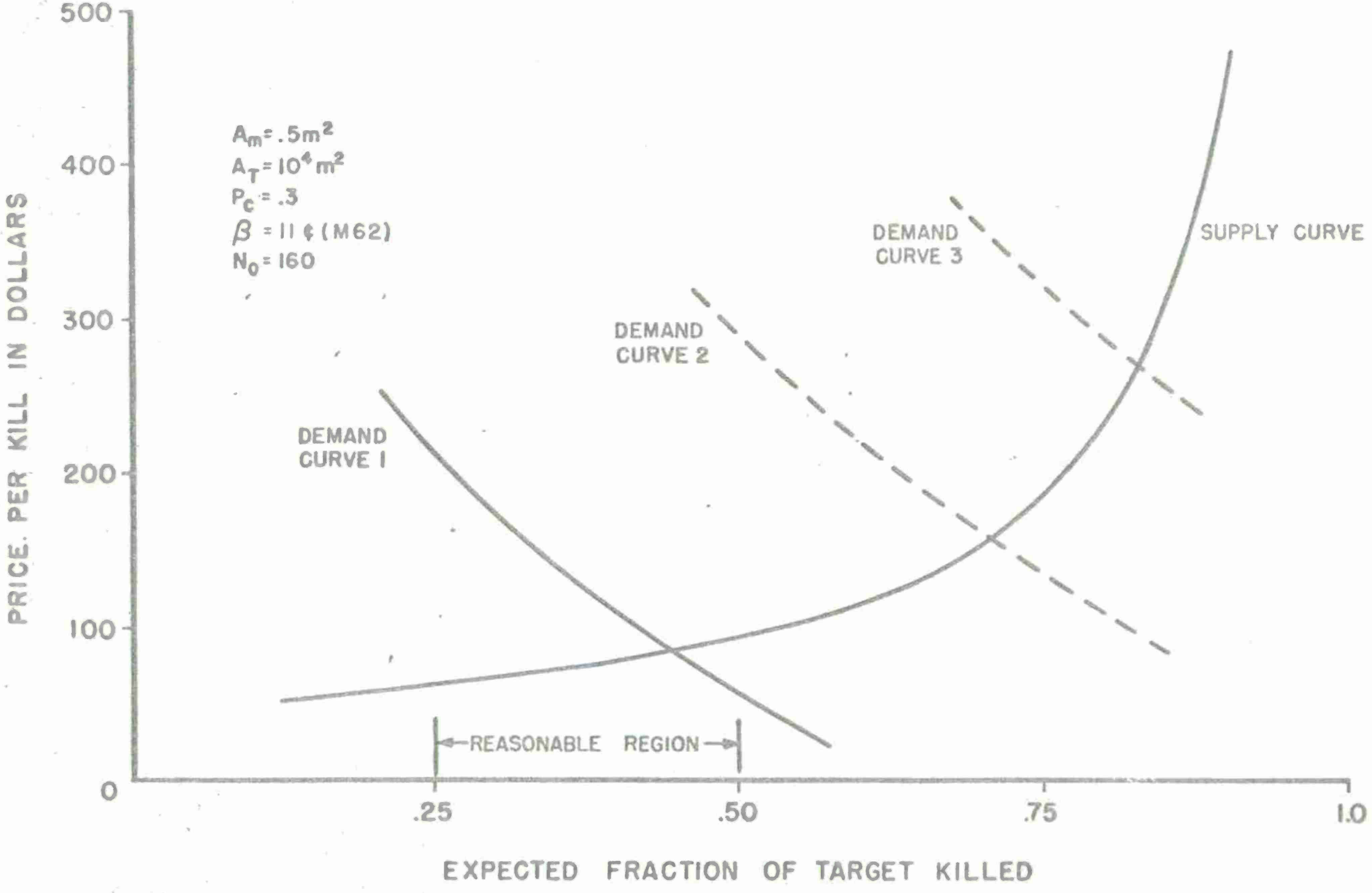
$$E(N) = N_o\left(1 - e^{-n\frac{L_A}{A_T}}\right) \qquad \text{for which } A_T \gg L_A$$

where L_A is the lethal area of the fragmentation weapon.

The method can also be applied to a mixture of infantry weapons attacking a given target area provided the model is suitably modified to account for the firing order of the weapons and target attrition between weapon usage.

CASUALTY SUPPLY AND DEMAND FUNCTIONS

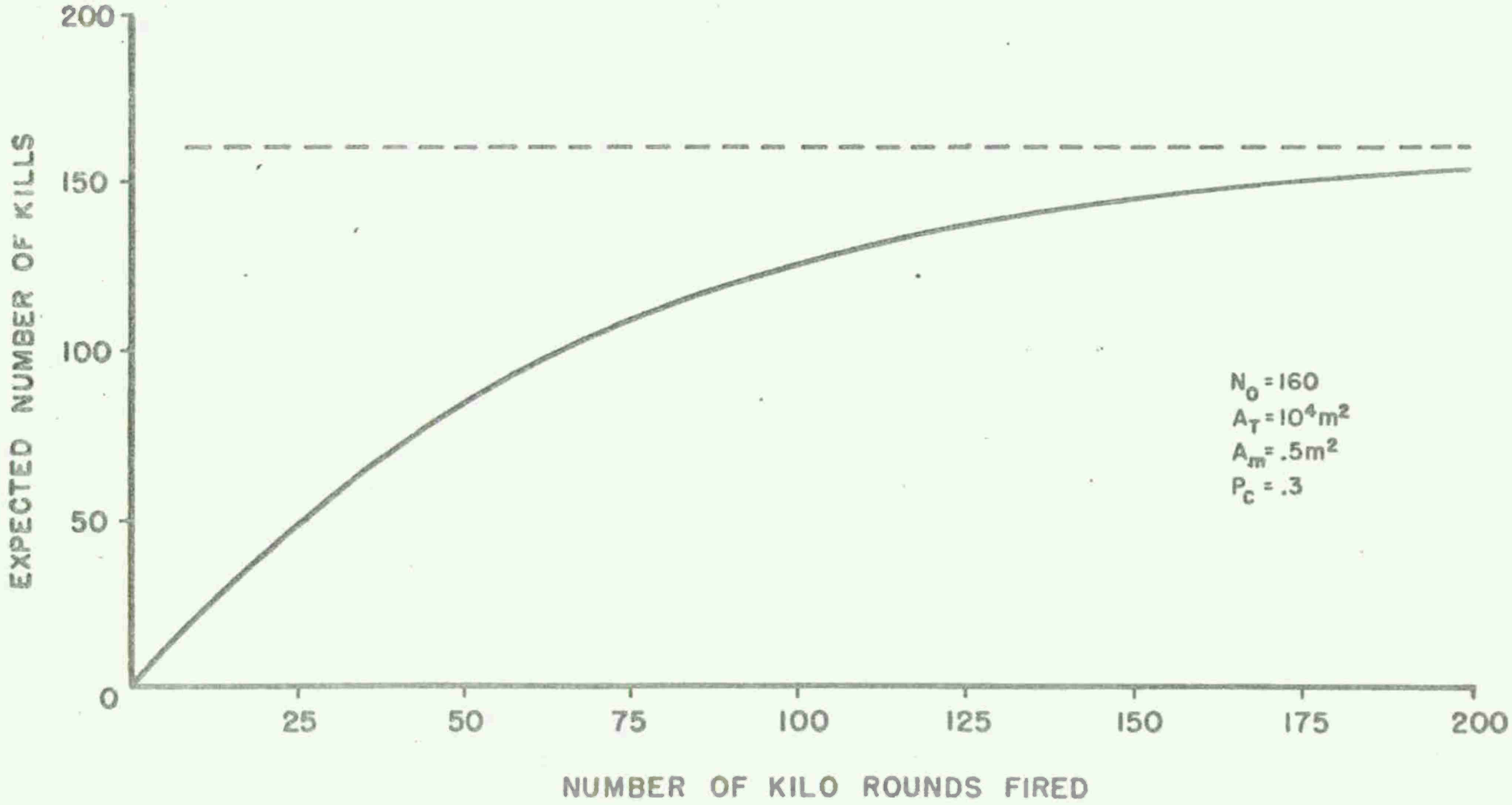
7.62 MM AMMUNITION



CASUALTY PRODUCTION FUNCTION

EXPECTED NUMBER OF KILLS ON AN INFANTRY COMPANY

5.56 MM OR 7.62 MM BALL AMMUNITION



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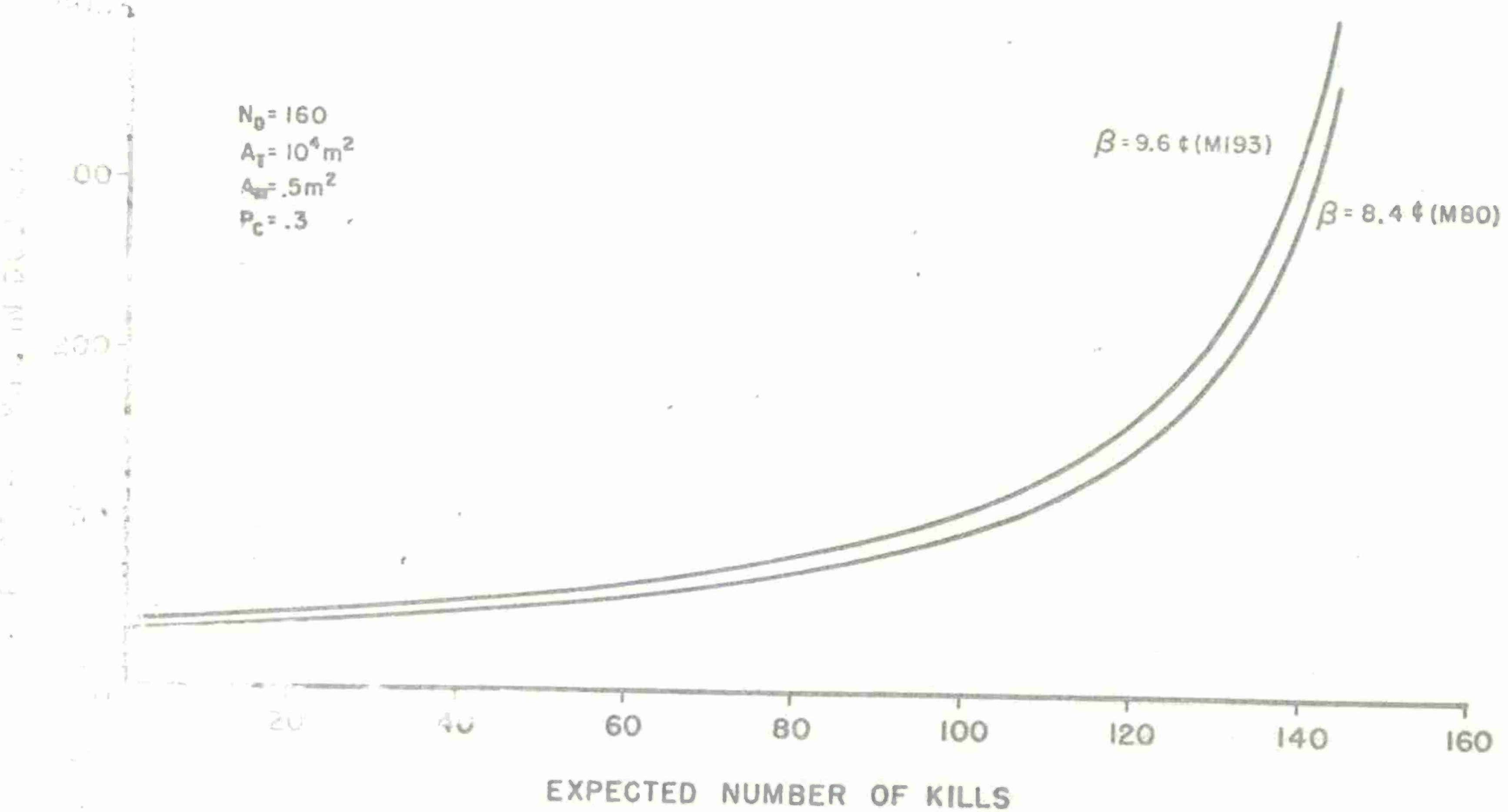
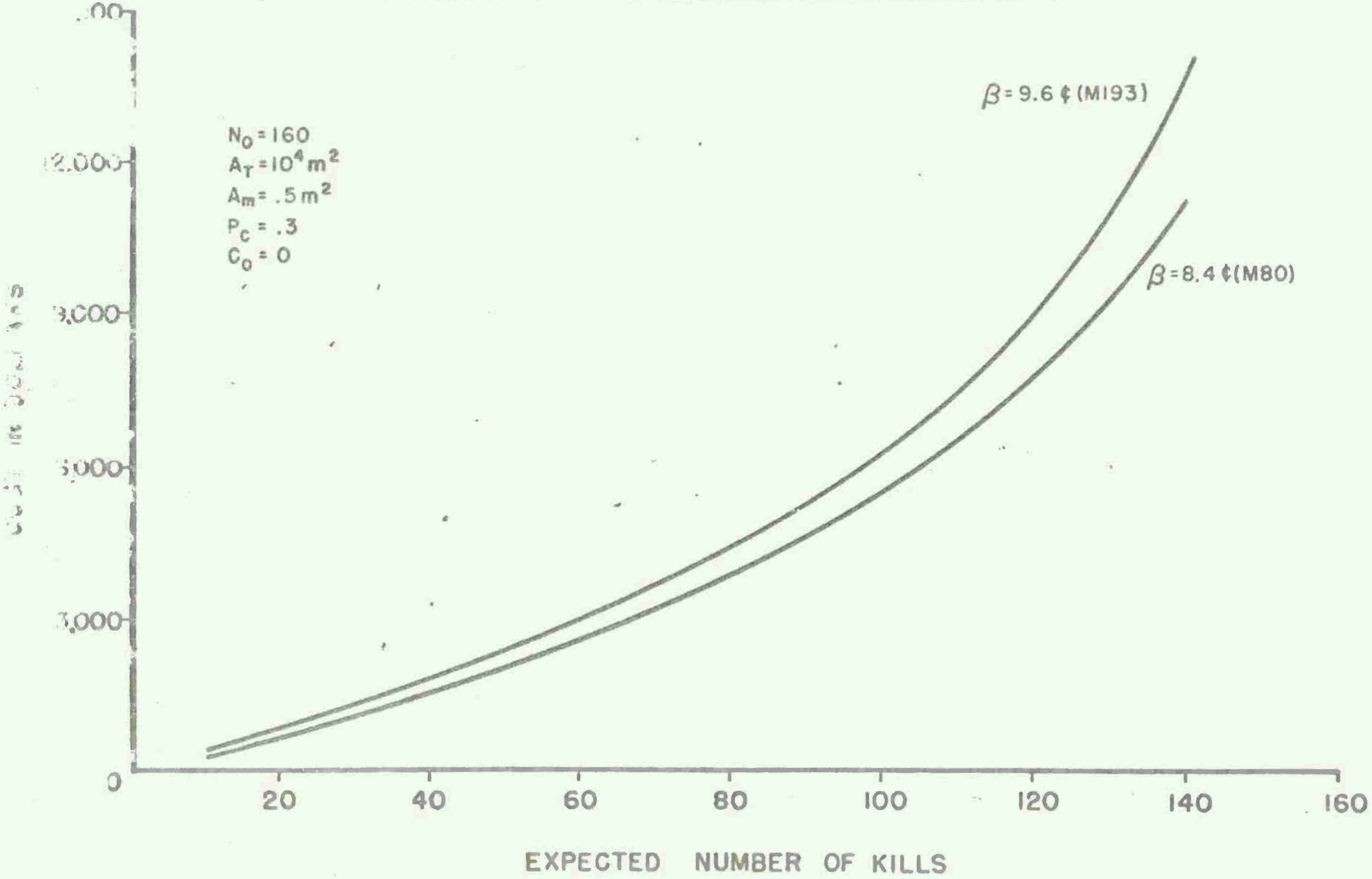
CASUALTY SUPPLY FUNCTION

5.56MM AND 7.62MM BALL AMMUNITION



COST TO KILL A FRACTION OF AN INFANTRY COMPANY

5.56MM AND 7.62MM BALL AMMUNITION



War Gaming -

From the Producer and Consumer Point of View

Martin W. Brossman (Session Organizer and Chairman)
Planning Research Corporation

Cognizant Agency: Army Materiel Command

Discussions of war gaming - more appropriately titled gaming - generally tend to emphasize the development, structure and results obtained from gaming. Little attention is given to gaming from the point of view of the user and the problem he is attempting to resolve.

The deficiency in exchange is critical both from the "consumer" and "producer" point of view. For example, games designed to assist on solution of problems of broad scope and importance are generally only one of many analytical approaches used to attack the problems. Thus the interrelation of the game to other techniques of analysis is seldom placed in prespective. In addition, it is seldom possible to determine how and in what way the game affected the consumer decision or in what way the game was responsible to the user requirement.

This session was organized to bring together the "producer" and "consumer" or potential consumer - in an effective exchange. It is designed to place gaming in more proper context from the consumer point of view.

War Gaming From a Consumer Point of View

Colonel Norman Farrell
US Army Institute of Land Combat

1. The Consumer Does Not Get a Free Ride. The most damaging thing a consumer of war gaming can do, having decided that war gaming could be useful to the solution of his overall problem, is to engage the services of a war gaming activity, no matter how competent it may be, and ask it, without elaboration, to "run a war game for him on such and such a subject." The results are not apt to fulfill his expectations; if they do not, the mismatch of consumer-producer is apt to reflect not only on the consumer in fulfilling his obligations but on the innocent war gaming agency through its participation in a failure.

2. Extensive Analysis Must Precede a War Gaming Directive. The consumer must determine what we call the Essential Elements of Analysis at the beginning of his overall effort. There are a small number of questions of major import, the answers to which are necessary before his overall study or investigation can be completed. The questions can be derived best by thoughtful and detailed consideration of the purpose of the study and in collaboration with whoever asked to have the study performed. After these EEA are derived, each of them must be considered to determine if it can best be answered through war gaming or simulation or some other method. This determination should be made by persons skilled in the techniques of operations research.

3. A Detailed War Gaming Directive Should be Prepared and Coordinated With the War Gaming Activity. The consumer must express as clearly as possible the objectives of the war game. These, of course, should lead to answers to those EEA which he has felt can be obtained by war gaming. No objectives should be listed which are not part of his EEA. To add other objectives to the game is to waste resources. The directive should include a scenario (how we got into this mess) in the preparation of which he can usefully accept the help of the gaming agency. Special attention should be paid to specifying the nature, extent, tactics, and weaponry of the enemy forces. Special care by the consumer is necessary in this area since the enemy in the war game must be compatible with the enemy postulated in other portions of the study than the war game. This frequently will do violence to the data banks of the war gaming agency or to its estimates on enemy potential for the time period. Fixing of the enemy details, however, is an important responsibility which cannot be delegated to the gaming agency. Details of the friendly force structure, equipment, and tactics, of course, also should be specified by the consumer. Extensive discussion face to face between the consumer and the producer of the war game is necessary prior to agreement upon this study

directive. These discussions should cover the producer's belief that the objectives can be met validly by the method of his war game; whether the data desired or the analyses required from the game can be produced by the consumer's required date; and elaboration, understanding, and agreement on the details contained in the directive.

4. The Consumer Must Monitor the Progress of the War Game. This in no way implies lack of confidence in the game producer, but is a service beneficial to both. The consumer remains aware of the progress of the game and may adjust his completion schedule or may ask to have adjustments in the gaming schedule. He anticipates and observes critical tactical events in the play of the game. He may feel it necessary to have side analyses performed by the producer or elsewhere. He forms an opinion as to the play of the game in order that he may make a meaningful analysis for himself of whether the outcome has been unduly influenced by player or controller actions. He becomes as familiar as possible with the methodology of the war game in order that he may assess for himself the validity of the methodology, both as it is written and as it was applied. He is alert to request variations in tactics, strengths, organization, or equipment as far in advance as possible. Sometimes repetitive plays of the basic game may be performed in which one key input is varied. Early knowledge of these repetitions assists the gaming agency.

5. He Must Critically Review the War Game Report. He does this in order to evaluate the performance of the producer. He compares the data, conclusions, and insights from the war game with the EEA which the game was designed to address to determine the need for additional gaming or for attainment of objectives by some other means, or to suggest to the producer improvements in his methodology.

6. Within the limits of his security problem he should convey to the producer the use which he has made of the war game effort and how it affected his overall study. He should also indicate the degree to which the game did or did not satisfy his needs.

WAR GAMING FROM THE PRODUCER POINT OF VIEW

by

Mr. L. J. Dondero
Research Analysis Corporation
McLean, Virginia

FACTS AND ASSUMPTIONS

Analytical studies and iterative simulations have still a long way to go to deal convincingly with military choice problems that are not confined to a single functional area with a set of clear and exclusive objectives.

This is not to say progress has not been substantial, but we really still don't know much about weapons choices that cross functional areas; e.g., the selection of optimum mixes of tac air and ground maneuver units.

A related problem, of course, is that of attempting to synthesize conclusions about respectively higher echelons in military organization, even if we think we have discovered something defensible about the appropriate composition and function of lower echelons. In other words, while we may be encouraged about an ability to design a company, given some agreement on its explicit functions, we cannot then readily move up the scale of aggregation to divisions, corps, and armies, by lumping companies of various functions in any optimum way.

I am not implying, by these statements, that war games can completely fill the gap as surrogates for analytic models and computer simulations. I think they have something useful to offer, despite their expense and slowness, but they _too_ have a long developmental path still ahead.

Thus, I guess my principal premise or assumption is that for awhile we cannot avoid using war games, despite their relative primitiveness, to get some handle on, some insight into the problems of force organization or size that we are confronted with. In order to live with games, then, we need to know what they _can_ do, and what they _cannot_ do, and therefore what users shouldn't expect of them.

SOME THINGS GAMES CAN'T DO

Despite recent efforts in comparative gaming of alternative mixes of combined arms, we don't yet feel we can throw much definitive light

on force composition problems. This is, of course, because of the gross way in which we measure effectiveness, i.e., by movement of attacker as a function of some gross organizational strength characteristic, as grossly modified by terrain, casualties, force posture, and the like. Thus, a series of games involving changing proportions of combined arms, within a given structure may reveal consistent differences of outcome, but this is because of factors inherent in the assessment models and not because the games are developing insights into the synergistic effects of combined arms in different combination.

About the best we can do with these kinds of questions is something of the sort we did with AAFSS, i.e., a comparative game involving two corps, one with and one without AAFSS. We know about the relative effectiveness of the two corps, but what we can say about the effectiveness of AAFSS, was in a sense, input to the game.

Or, another illustration would be the nine games we played in ARCSA II, in which a single U.S. division was played in three different areas of operations, in the ratio of 1, 3, 8, with three different levels of supporting aircraft, in the ratio of 1, 2, and 4. In terms of geography and mission, we were able I think to indicate some useful data on division effectiveness as a function of aircraft. But this is only the beginning of the optimizing problem.

Another thing that games cannot do, that we feel we are sometimes being asked to <u>make</u> <u>them</u> <u>do</u>, is to <u>generate</u> the performance or effectiveness factors associated with a new weapon system. In other words, we feel occasionally that the game objectives are written in such a way as to imply a hope that out of the game will come certain measures of performance, that really must be <u>input</u> to the game. A new weapon system, or a new doctrine of tactical employment, can be evaluated in the course of game play in an open, explicit, and systematic way, in a tactical setting that is reasonably realistic in the space, time dimensions, but the war game cannot generate kill probabilities, flight profiles, and other intrinsic characteristics of the weapons played in the game.

A third caveat about the nature of present-day games is that in games things work unrealistically smoothly in the command, control, communications area, and in other functional areas, where real people get lost, tired, confused, and indifferent to the fact that they are all of these things. In other words, the only mistakes made in a war game are occasional human errors of recording what happened. As a consequence, the pace-of-events probably is considerably more rapid than it could ever be in real war, and any given number of days of game combat may incorporate a degree of activity and intensity that would leave a real-world combat unit exhausted in only a fraction of the time depicted. For these reasons I am always a little uneasy when I see game output data,

related especially to logistics, used in too literal a sense. On the basis of ARCSA games, which I have already cited, we can say some useful things about the impact of relative levels of logistic support; but before I used a short-duration war game as a generator of logistic loads, I would want to satisfy myself as to the extent to which the pace of events was artifically accelerated. Furthermore, although we do attempt to incorporate factors for combat degradation as a function of logistic degradation in our games, we are forced to admit that these relationships are perhaps arbitrary, and in any event, being of a linear character, they are naturally suspect.

WHAT GAMES CAN DO

Having said all these nasty things about the limitations of gaming, I now wish to indicate some reasons why they remain useful despite their limitations.

The first reason is fairly obvious. In a situation in which the variables are so numerous and poorly defined and in which the empirical evidence from history is so sparse, there is no reasonable substitute for a methodology which enables one to consider most of the variables in something approximating their real world, spatial, temporal, and organizational dimensions. The problem of deciding on the appropriateness or value of a new weapon system or doctrine could, of course, be solved on the basis of intuition or experienced judgment, but the advantages and disadvantages and their relative influence can be much more clearly appraised, when all the variables are allowed to interact on each other in the same manner and to the same degree that they might interact in the real world. In brief, the war game provides a comprehensive tactical context for exercising concept and doctrine.

I am not sure that in every case such an exercise is better than intuition and experience, but it does have the virtue of being open, explicit, and reproducible. By that I mean simply that any number of users of the game output can know exactly what the inputs and manipulations were and judge for himself their validity and, if necessary, perform reevaluations in the same explicit methodological terms.

The third reason why I think that games of the kind I am describing will continue to be useful is that they can take account of the decision making or managerial function of typical military officers. The proper evaluation of weapon systems, doctrine, and force requirements should include, of course, such decision making functions for the simple reason that there is obviously an important interaction and feedback between the character of decisions and perceived effects of weapons and doctrine.

Finally, I would stress as a useful feature that the structure and outputs of games of this sort can be expressed in terms that are operationally significant to the military decision maker. That is the models and submodels depict familiar military functions, e.g., firepower and maneuver, logistics, etc., and relate these to the outcome of the battle in concrete terms that are part of the military man's tradition. A pure computer simulation on the other hand may tend to be couched in generalized mathematical relationships which define the functions and outcome of combat in terms that are abstract to the military man. This is not to say that it is not possible to construct comprehensive computer simulations that closely parallel the structure of current war game models. I am suggesting merely that the outcomes of more generalized and aggregated simulations are probably not nearly as acceptable or understandable to the military evaluator as those of the war game.

In sum, it seems to me that short of war or extensive field experiments, games are indispensable tools for systematic and explicit appraisal of many questions too complex for intuitive solution.

WHAT WE NEED FROM CUSTOMERS OF WAR GAMES

Although the foregoing is essentially introductory to the main theme of this panel, namely what the war game designers and players would like to have understood by war game customers, everything I have said so far suggests the outline of what follows:

(1) The war game customer should carefully examine his requirements to determine that what he is asking of the game is not really of the nature of game input.

(2) He should discuss with the game builders and operators the statement of given objectives so as not to impose on the gamers requirements for a given output that a gamer knows his models cannot produce.

(3) He should attempt to arrange a game schedule which ideally permits two things:

First, a duration of simulated combat from which it is reasonable to make extrapolations. Frequently because of compressed schedules we are asked to play 5 to 10 days of theater combat operations in one or two or three different phases of offense and defense. The hazards of extrapolation from this kind of simulated experience should be fairly obvious. There is, of course, a contradiction here because long duration games are more expensive and time consuming, but one should at least attempt to select a combat duration which he feels is adequate for

extrapolation and not simply accept a game duration because if fits a short term deadline with which he may be faced.

The second thing that he ought to try to do is allow time and resources for some degree of iteration or comparative gaming, as in the nine-game ARCSA series already mentioned, or the equal-cost corps games of the AAFSS series.

(4) He should satisfy himself on the persistent question of the credibility of the critical models in the sequence. The only way I know to do that is to review the principal features of these models beforehand and, on the basis of judgment, see if they seem to generate an output which doesn't flagrantly violate military judgment. Ground combat models, despite their increasing complexity of detail, are still fairly primitive, depending as they do on measures of relative force value that are based on firepower. We are always getting belabored by military users of games who say that these firepower measures are really not adequate for determining the outcome of combat. The two general kinds of criticisms are, first, that if you wanted to optimize a force structure you would use all tanks and artillery because that would generate the higher firepower score. But this comment is irrelevant because the firepower expressions now in use are simply the historical expressions of relative lethalities of the various combined arms when used in combination and roughly in proportion to their use in past wars. The second kind of criticism seems to be based on the assumption that a static firepower comparison predicates the outcome of battle and precludes other considerations, but in reality we do modify firepower in our games by considerations of mobility, maneuver, surprise, terrain and logistics. Admittedly the way we made these modifications may be arbitrary and judgmental, but in no sense do we regard the initial firepower calculations as deciding the outcome *a priori*.

(5) The war game customer should carefully appraise his objectives to determine the requisite level of aggregation or conversely the degree of detail that will be needed. The common tendency is to look for a game that provides an abundance of game output because the customer has a feeling that he may need a great deal of detail to support his position. But, of course, the more aggregated games are faster and cheaper and the tendency should therefore be to search for the highest level of aggregation consistent with the needs of the client. Also we sometimes get objectives stated in ways that would require laborous micro-gaming to satisfy some of the objectives whereas the others may be satisfied by games at higher level of aggregation. This creates certain inconsistencies, such as demands for using our theater-level simulations but at the same time playing nuclear weapons weapon-by-weapon, or AAFSS helicopters, helicopter-by-helicopter.

(6) The war game customer should, through liaison officers or actual participation, monitor the progress of a game in ways that serve

the cause of both producer and user. He may feel, for example, as a result of such close monitoring that he may want to alter the terms of reference or that the game has gone far enough for his purposes even though the initial plan carried it further, or that insights developed in the play of the game should alter the pattern of tactical employment and so on.

(7) Having stated the objectives and dimensions of the game the customer should allow sufficient time for a thorough post-game analysis by the game producer. This helps in two ways: the producer is more fully aware of the limitations of the model and thus less apt to generalize and extrapolate inappropriately; and second, being more familiar with the format of output, the game producer can more efficiently perform the tasks of data reduction.

(8) Finally, the war game customer, as often as he can, ought to give the producers some clue as to the extent to which the game was useful or not in his larger analyses, and if not, why not.

SIMULATION OF TRUNCATED QUEUING SYSTEMS WITH
CONSTANT AND TIME VARYING ARRIVAL RATES

Prepared by 1LT Ronald W. Meier
Engineer Strategic Studies Group
Office, Chief of Engineers

The purpose of this paper is to demonstrate a modeling technique that may be used to study a rather complex queuing system. Based on simulation, this method utilizes the engineering design-analysis approach of breaking a system down into its component parts. Development of this methodology is described in the paper and actual application to a typical system is presented.

Many real world systems can be mathematically structured as a queuing system with the following conditions:

1. The maximum number in the system (number in the queue + number in service) is limited to some finite number.

2. The arrival rate is not constant but is functionally dependent on time.

Perhaps the most obvious example of such a queuing system is the line at a theater. Since the capacity of the theater is finite, the maximum number of people possible in line is also finite. Using a Poisson distribution to describe the arrival process, a possible time history for the parameter $\lambda(t)$ is shown in Figure 1. The two sharp peaks are of course due to the schedule of the theater.

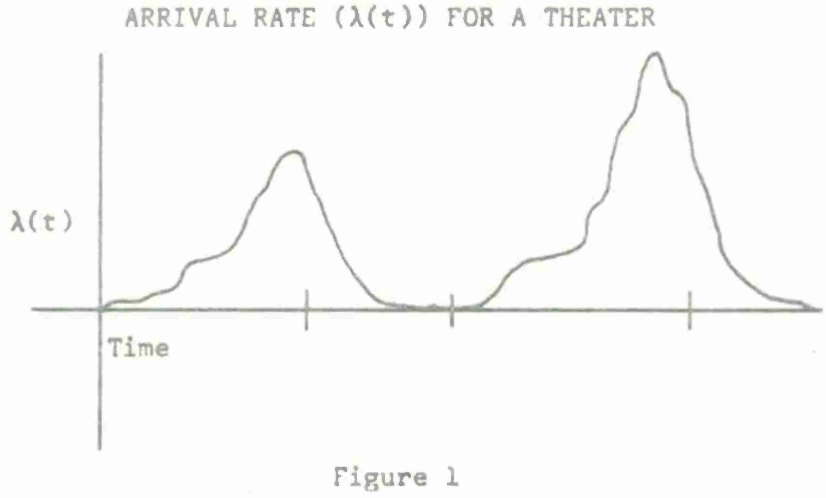


Figure 1

Another system which may be imbedded in this model is that of a gasoline service station. Since there is limited space available for automobiles to park on the apron the maximum queue possible is finite. The arrival rate of customers to a service station is not constant but has sharp peaks during the day. There are many other systems that could be formulated within the framework of this model.

The analytical solution to the problem of time-dependent arrival rates is outlined in Satty's book "Elements of Queuing Theory with Applications" McGraw Hill, 1967. This method of solution is limited and application to many systems is not effective.

Simulation provides a method for system analysis that obviates the need for complex mathematical analysis. Using simulation, the time history of the system is presented as output. Thus, both the transient and steady-state problems are solved. Some limitations are inherent in this methodology and will be discussed in depth later in this paper.

Since queuing systems can be described by differential equations, a natural computer choice for simulation is the general purpose analog computer. This computer provides a very flexible framework in which many types of systems can be structured. The methodology developed in this paper is predicated on analog computer simulation techniques.

Consider the queuing system with the following parameters:

L = Maximum number in the system

$\lambda(t)$ = Arrival rate (time dependent)

μ = Service rate (constant)/attendant

n = Number of attendants

$P_m(t)$ = Probability of m in the queue at time t

For the single channel queuing model with a Poisson arrival function one can write:

1. $P_m'(t) = -\lambda(t)P_m(t) + n\mu P_{m+1}(t)$; for $m = 0$

2. $P_m'(t) = +\lambda(t)P_{m-1}(t) - (\lambda(t) + n\mu)P_m(t) + n\, P_{m+1}(t)$;

for $1 \leq m < L$.

3. $P'_m(t) = +\lambda(t)P_{m-1}(t) - n\mu P_m(t)$

for $m = L$

Where $P'_m(t) = \dfrac{dP_m(t)}{dt}$

Figure 2 shows the analog computer circuit used to simulate the truncated queuing system where $L = 2$.

The initial condition (IC) is given the value of one. This represents the condition $P_0(0) = 1$. The function $\lambda(t)$ may be generated on the computer directly or obtained from some external input device. Outputs from the system can be plotted using some type of x-y plotter.

To demonstrate this method of simulation, consider the truncated queuing system with the following parameters:

1. L = Maximum allowed in system = 4 people

2. $\lambda(t)$ = Arrival rate = constant = 2.5 people/time unit

3. μ = Service rate = constant = 2 people serviced by each attendant/time unit

4. n = Number of attendants = 1.

This system can be structured mathematically as follows:

$$P'_0(t) = -\lambda(t)P_0(t) + \mu nP_1(t)$$

$$P'_1(t) = +\lambda(t)P_0(t) - (\lambda(t) + \mu n)P_1(t) + \mu nP_2(t)$$

$$P'_2(t) = +\lambda(t)P_1(t) - (\lambda(t) + \mu n)P_2(t) + \mu nP_3(t)$$

$$P'_3(t) = +\lambda(t)P_2(t) - (\lambda(t) + \mu n)P_3(t) + \mu nP_4(t)$$

$$P'_4(t) = +\lambda(t)P_3(t) - \mu nP_4(t)$$

Figure 3 displays the time histories for the probability functions $P_m(t)$; $m = 0, 1, 2, 3, 4$; $t = 0$ to $t = 10$. Since the queue is truncated the fact that the average arrival rate is greater than the average service rate does not imply system instability. In this case, steady state is reached after 6 time units.

ANALOG COMPUTER CIRCUIT DIAGRAM

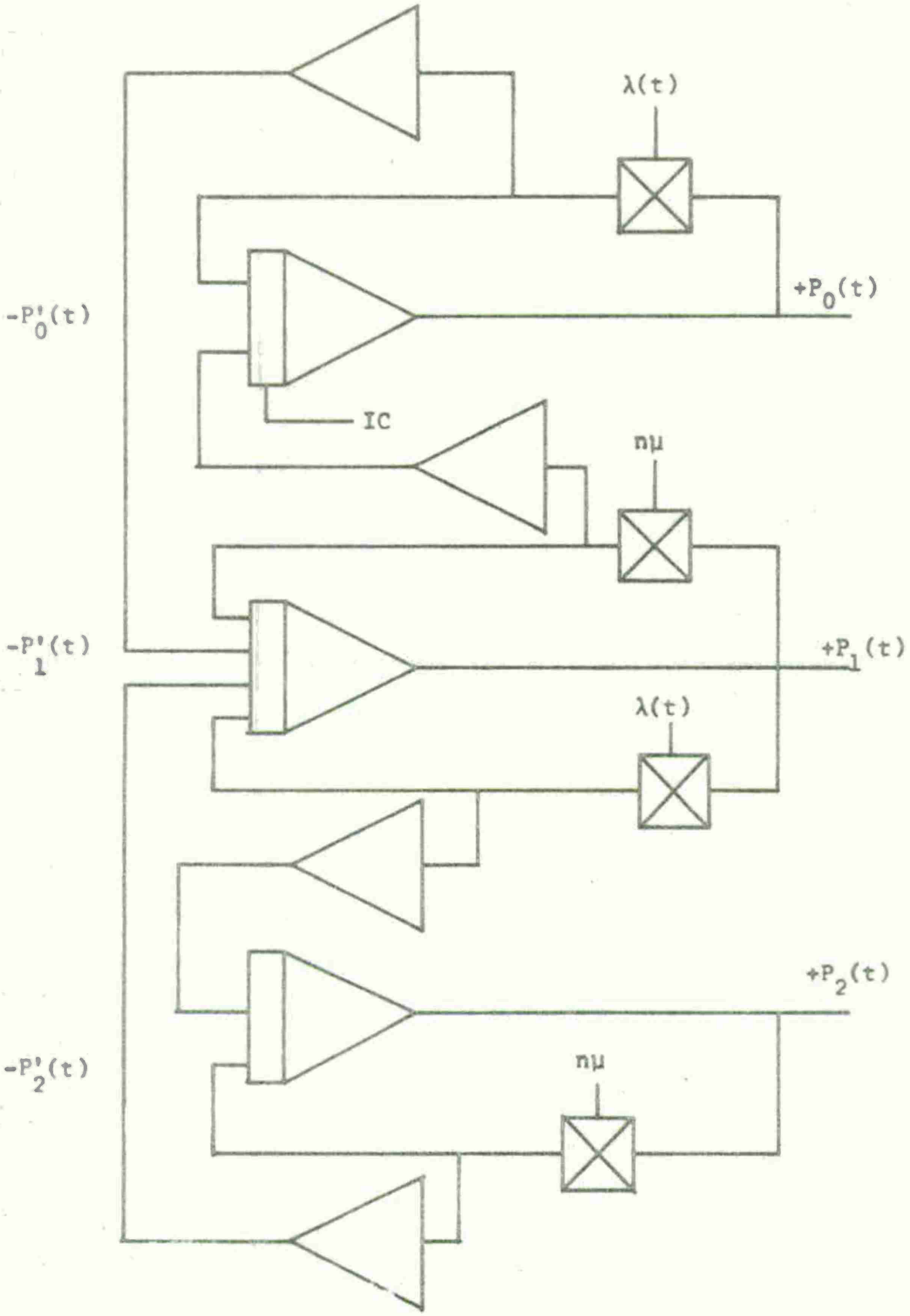


Figure 2

PROBABILITY FUNCTIONS vs TIME
($\lambda(t)$ constant)

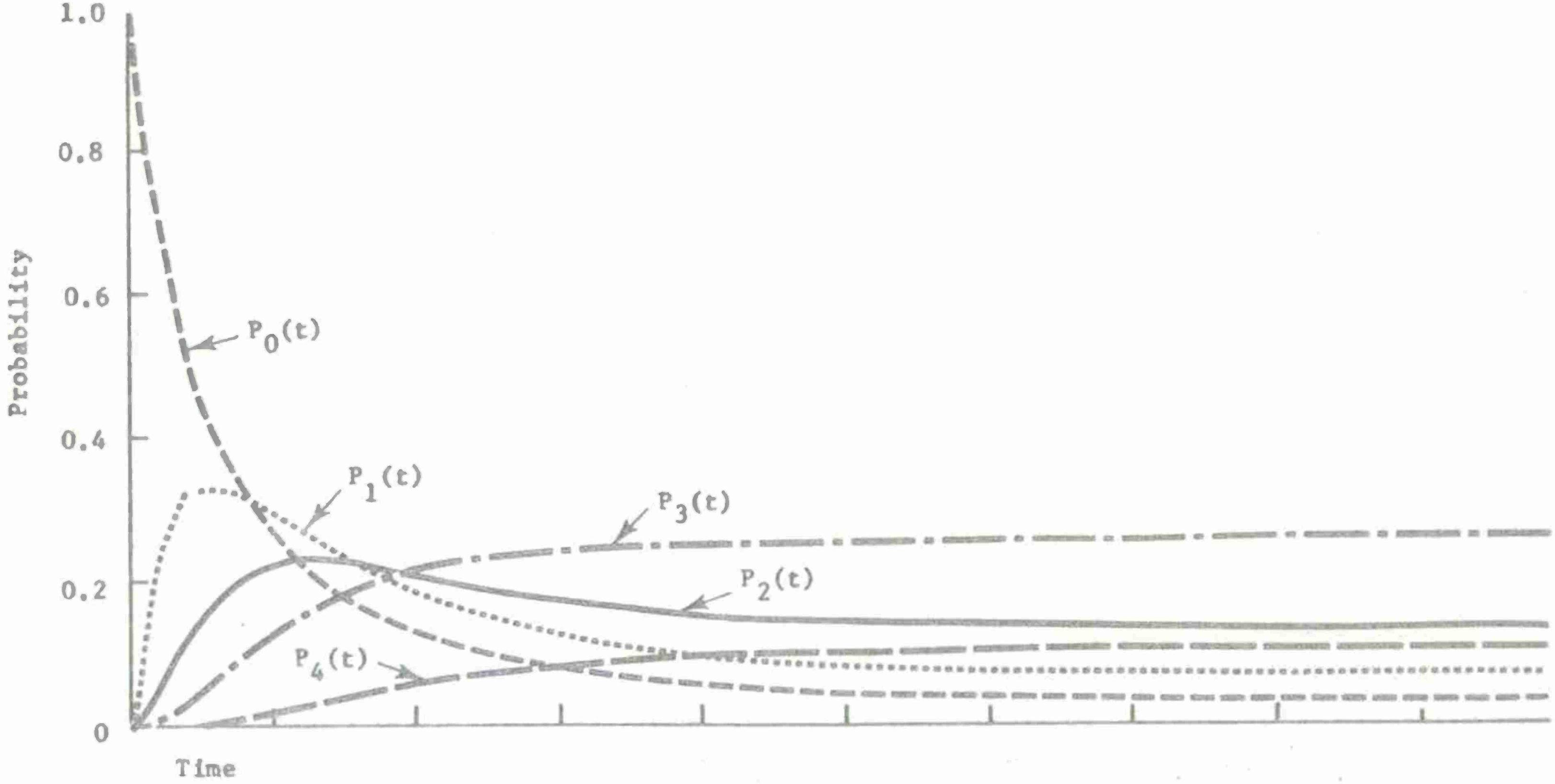


Figure 3

A problem that often arises in queuing systems is that of balancing the cost of service against the cost due to loss of customers. Consider a gasoline service station with room for only four automobiles on the apron. With the provision that automobiles are not allowed to form a queue in the street, the apron size constraint now dictates possible loss of customers when four automobiles are in the system. Assume that the rate of service ($n\mu$) can be increased linearly by the addition of more attendants. As the number of attendants (n) increases, $P_4(t)$ decreases and the number of customers lost also decreases since the rate of loss of customers can be expressed as: (probability of 4 in the system) (the arrival rate).

If:

α = cost/unit of service rate (μ)

β = cost/unit of loss of customers

then the total cost of service from start of operation to some terminal time T is:

$$\int_0^T \alpha n\mu dt$$

Total cost due to loss of customers for the same time period can be expressed as:

$$\int_0^T \beta P_4(t)\lambda(t)dt$$

Figure 4 shows the additional circuitry that must be added to the model for cost evaluation. The output C(t,n) can be expressed mathematically as:

$$C(t,n) = \int_0^T |P_4(t)\lambda(t)\beta - n\alpha\mu|dt.$$

The functional relationship between C(T,n) and n is such that as n increases from zero, the values of C(T,n) form a concave function. A minimum value of C(T,n) will be attained for some finite value of n. Figure 5 shows a typical plot of C(T,n).

From this graph it is obvious that when n = a an economic tradeoff between cost of service and cost due to loss of customers has been reached.

While the final value of C(T,n) is a good criterion for determining the optimum value of n, much knowledge can be gained by looking at the time history of C(T,n). To demonstrate, consider the following system:

COST EVALUATION CIRCUIT

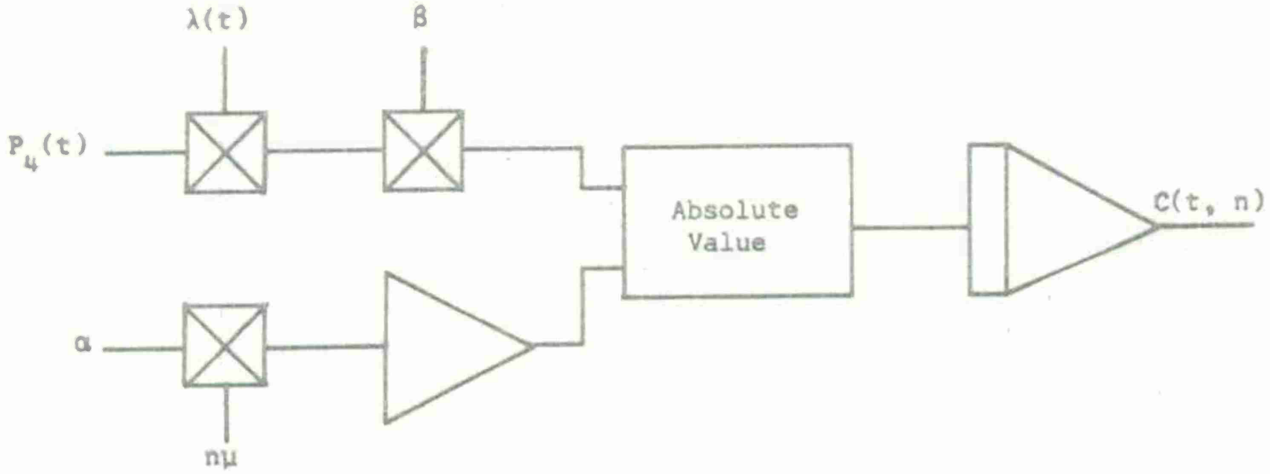


Figure 4

A TYPICAL GRAPH OF C(T, n)

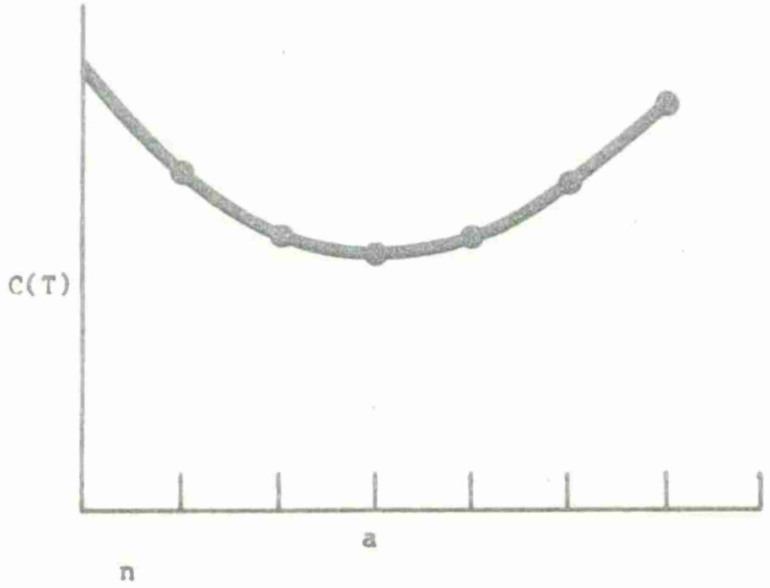


Figure 5

1. $L = 4$ customers

2. $\lambda(t) = 1.5$ customers/time unit

3. $\mu(t) = 1.0$ customers serviced by each attendant/time unit

4. n = Number of attendants

5. α = \$1.00 = cost of each unit of service

6. β = \$3.50 = lost income/customer turned away because the system is full.

Time histories for the functions $C(t,n)$ with $n = 1, 2, 3$ are shown in Figure 6. It is evident that with $n = 2$, the terminal value of the function $C(t,n)$ is a minimum. The cost \$12.50 represents the cost associated with loss of customers and idle time.

Computer output as displayed in Figure 6 provides the analyst with information concerning fluctuations in the function $C(t,n)$. It may be possible that this continuous history will be of more value than just the terminal value $C(T,n)$

When $\lambda(t)$ is constant, the function $C(t,n)$ will assume a linear form the moment the functions $P_m(t)$ reach steady state. This is clearly shown in Figure 6.

When $\lambda(t)$ varies as a function of time, the functions $P_m(t)$ may never reach steady state. To demonstrate this, consider the following system:

1. $L = 4$ customers

2. $\lambda(t)$ = Function of time

3. $\mu(t)$ = Constant = 2 customers/time unit

The time history for $\lambda(t)$ is shown in Figure 7. The function $\lambda(t)$ varies from 0.8 customers/time unit to a maximum of 2.3 customers/time unit, with an average of 1.5 customers/time unit.

Figure 8 displays the resulting probability functions. It is interesting to note that no steady state is ever reached by the system. It is this fact that makes the analytical solution so difficult. Since the functions $P_m(t)$ never reach steady state, it is logical to assume

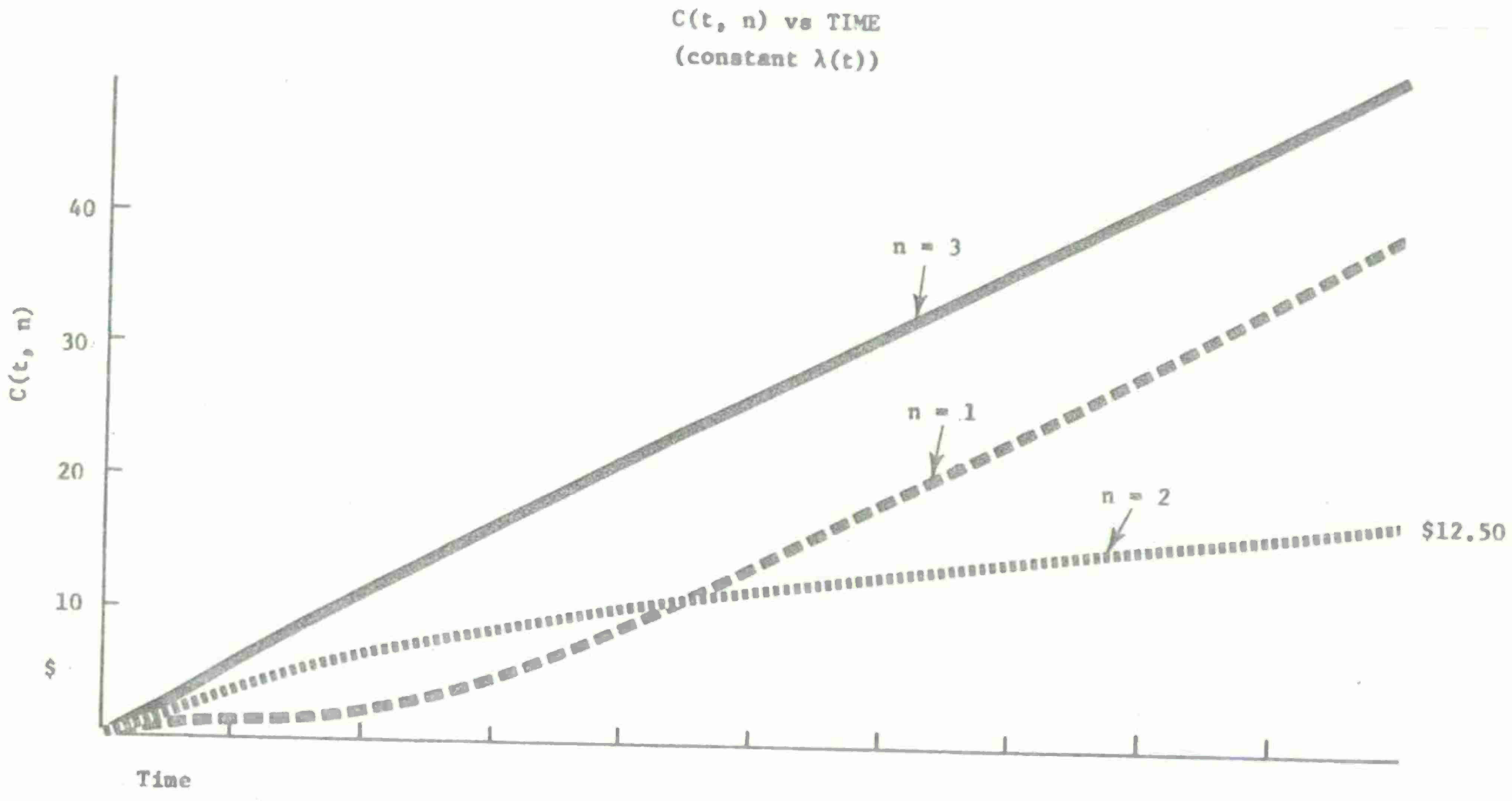


Figure 6

TIME HISTORY OF λ (t)

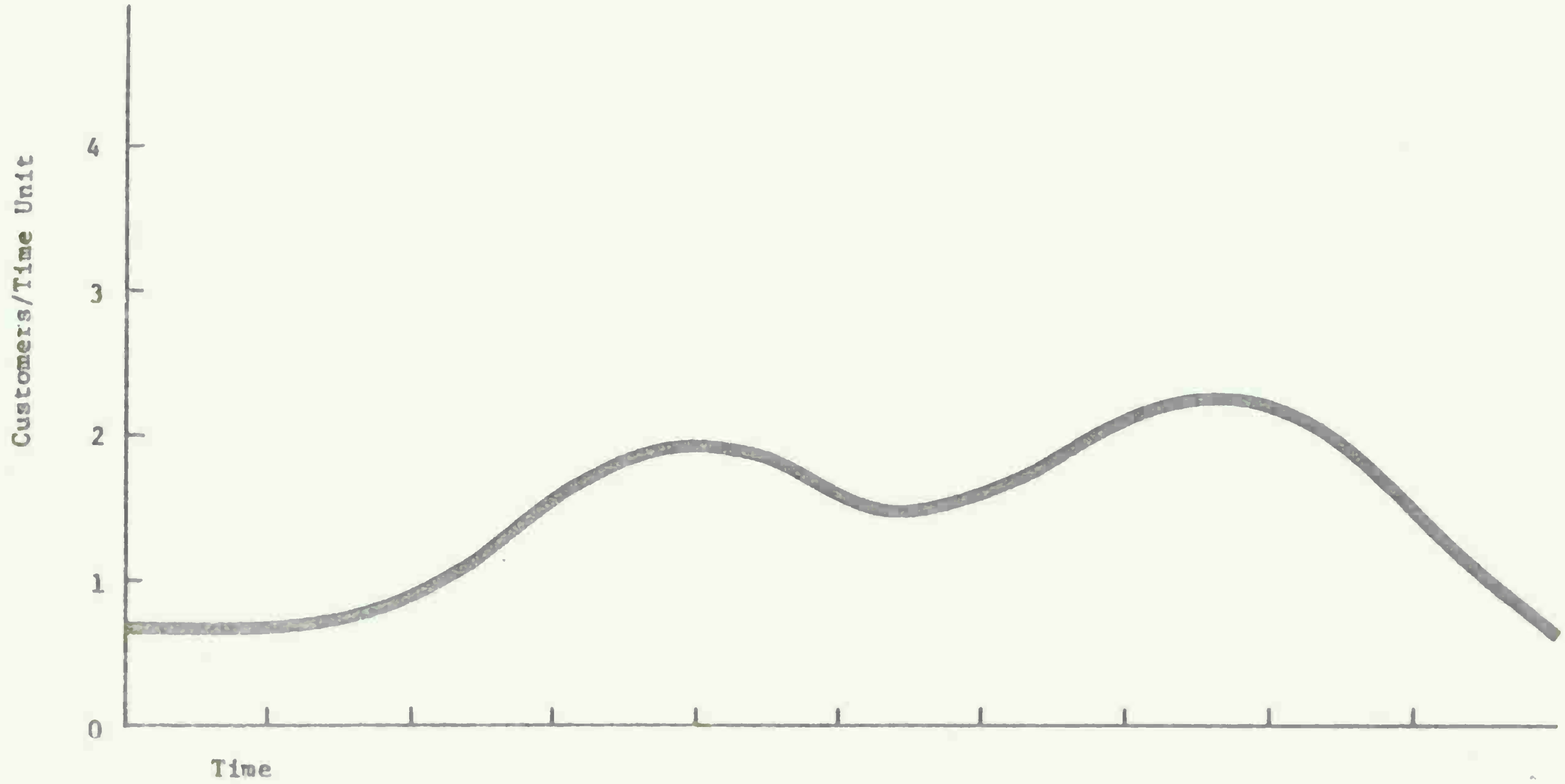


Figure 7

PROBABILITY FUNCTIONS vs TIME
(time varying λ(t))

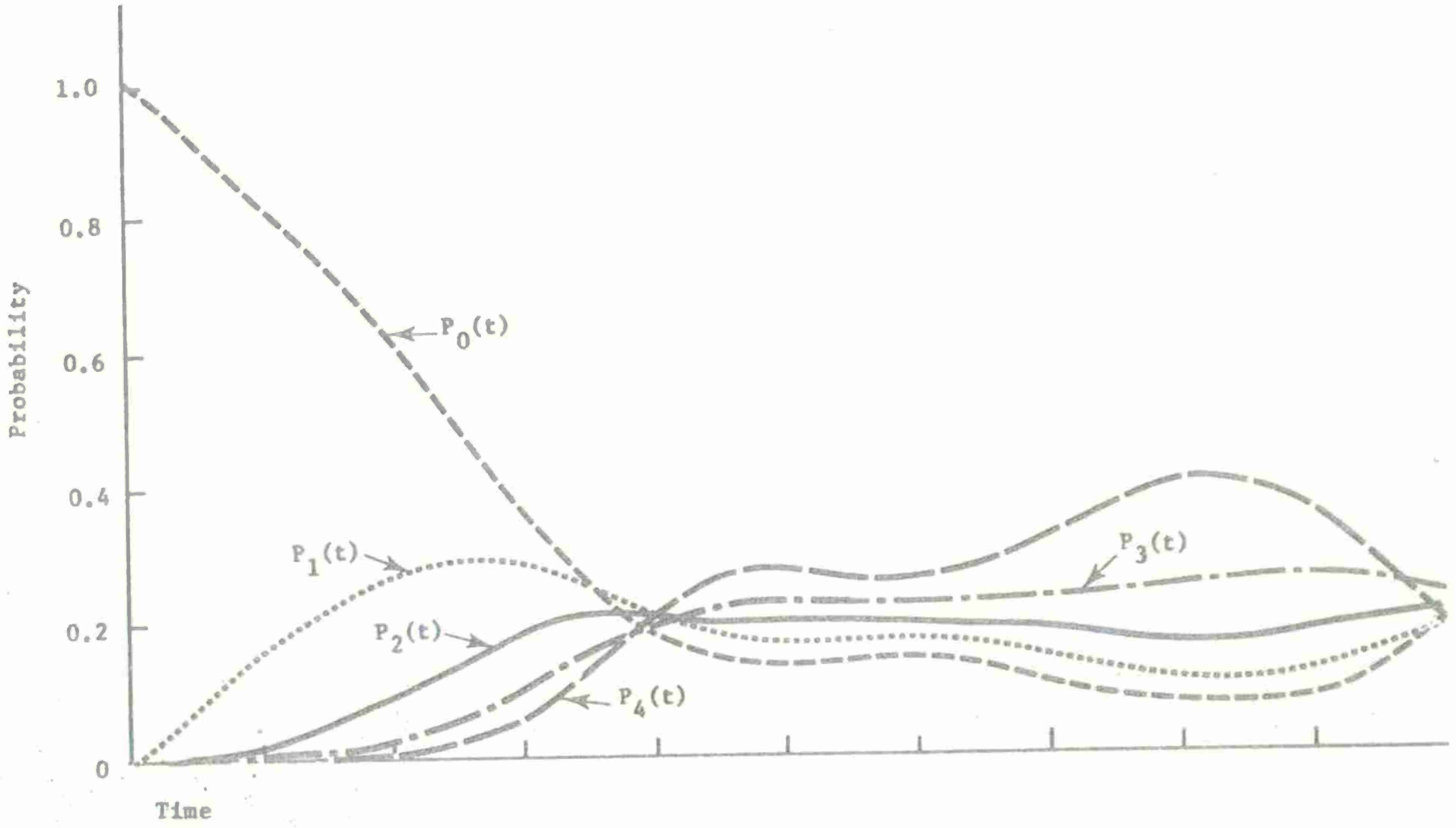


Figure 8

that the form of the cost function $C(t,n)$ will no longer be linear. This fact is clearly shown in Figure 9. The values of α and β were the same as those used in Figure 6, namely α = \$1.00 and β = \$3.50. Thus, by using the time function $\lambda(t)$ rather than the average value ($\lambda = 1.5$) the cost has increased from \$12.50 (Figure 6) to \$27.50 (Figure 9). It is interesting to note that the optimum value for n is still $n = 2$.

The inadequacy of a constant service rate to satisfactorily cope with a fluctuating arrival rate dictates the need for a more responsive service schedule. If the manpower resources are such that men can be used for intermittent service, feedback loops can be designed to generate the appropriate service schedule. While a complete discussion of this method is beyond the scope of this paper, some comments and examples are in order.

Since the queuing system model consists of a series of first order systems, large time constants are inherent. The time constants associated with the functions $P_m(t)$ increase with m. If the object of the control function is to balance the cost of service with the cost due to loss of customers, then the functions $P_L(t)$, $P_{L-1}(t)$ . . . $P_0(t)$ must be monitored in this order. Since $P_L(t)$ displays the largest time constant the optimum feedback should anticipate changes in $P_L(t)$. In designing such a feedback network, advantage can be made of the constraint:

$$\sum_{m=0}^{L} P_m(t) = 1 \quad \text{for all } t.$$

A block diagram for a typical feedback system is shown in Figure 10. The configuration shown in Figure 10 is very general and appropriate modifications would be made in actual system application.

Figure 11 shows the cost function $C(t,n)$ when n is generated by a feedback network. The output of the feedback loop was constrained to be an integer value with $0 \leq n \leq 3$. The cost was reduced from \$27.50 (Figure 3) to a value of \$2.25 (Figure 11).

The service schedule ($n(t)$) required to achieve this reduction is shown in Figure 12. In practice this schedule may be too erratic for effective application. This problem can be eliminated by either modifying the feedback network or simply smoothing the service schedule $n(t)$.

The probability functions are displayed in Figure 13. The rather abrupt changes are of course due to the discrete nature of $n(t)$. It is interesting to note that the system has almost achieved a steady state solution. A comparison of Figure 13 with Figure 8 reveals how powerful

C(t, n) vs TIME
(time varying λ(t))

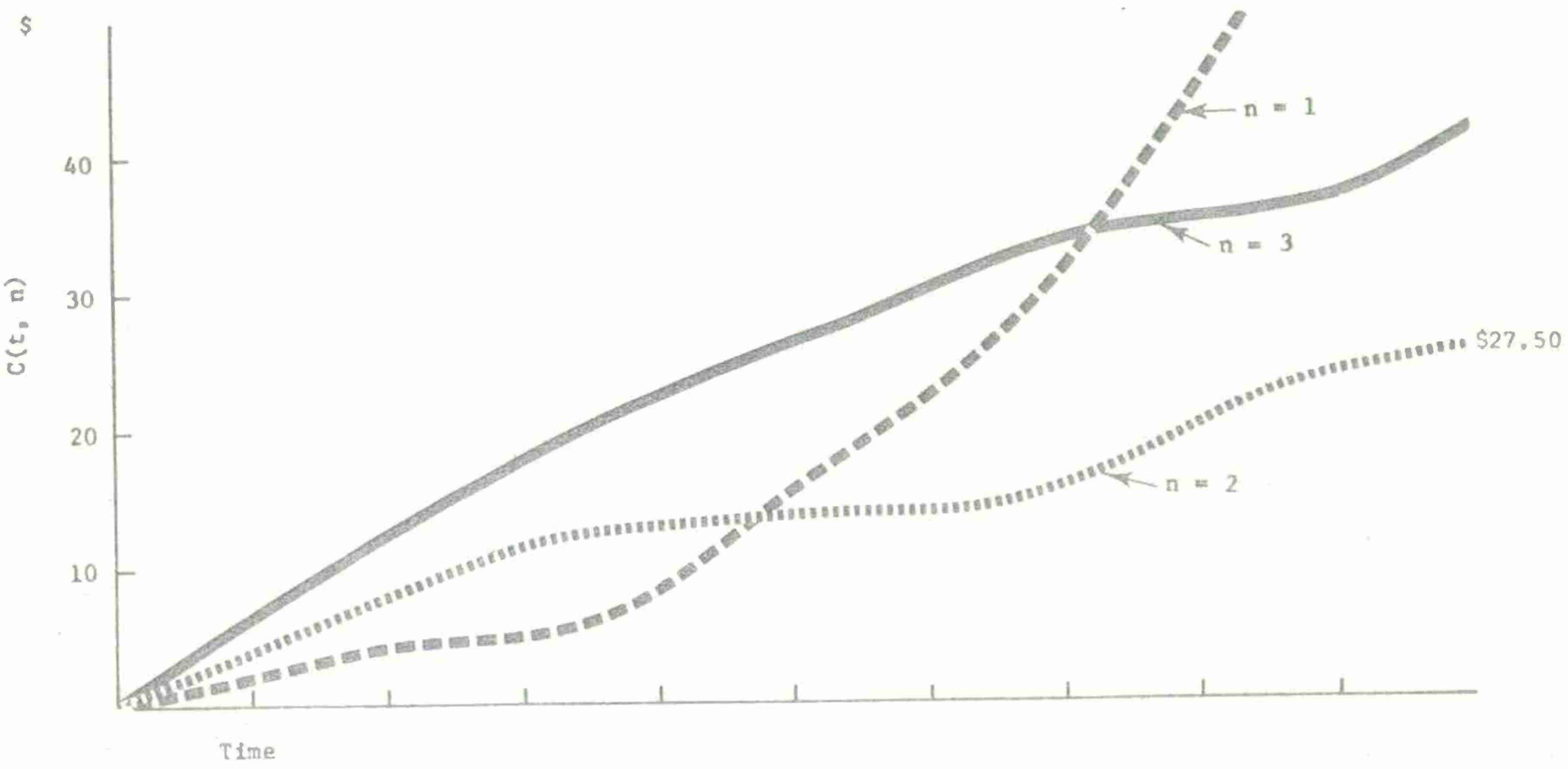


Figure 9

GENERAL FEEDBACK CONFIGURATION

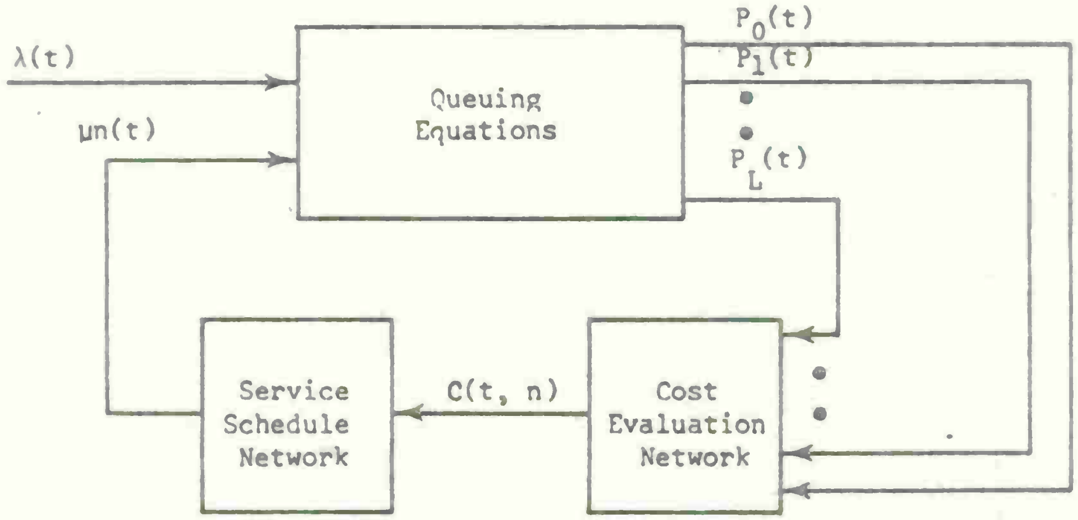


Figure 10

C(t, n) vs TIME
(with feedback)

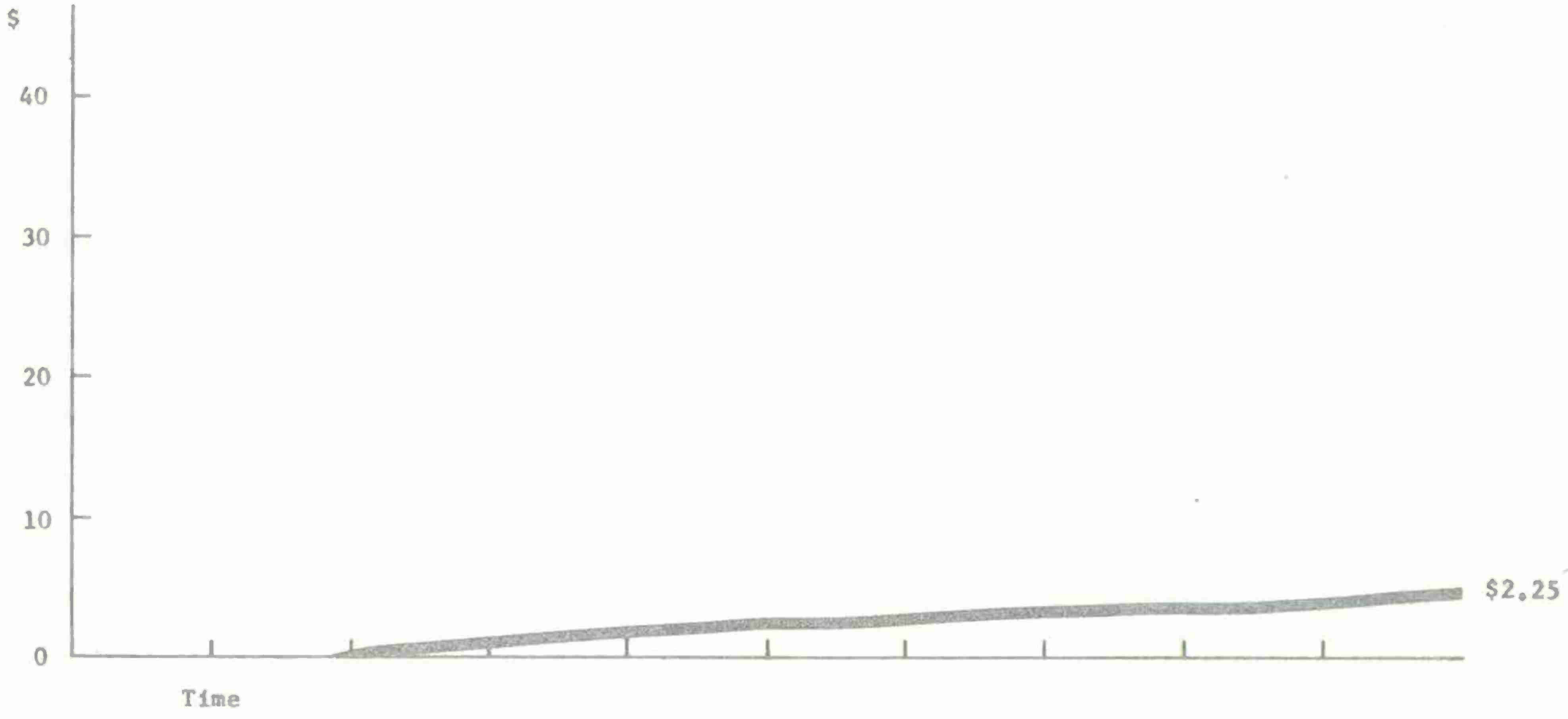


Figure 11

SCHEDULE FOR ATTENDANTS

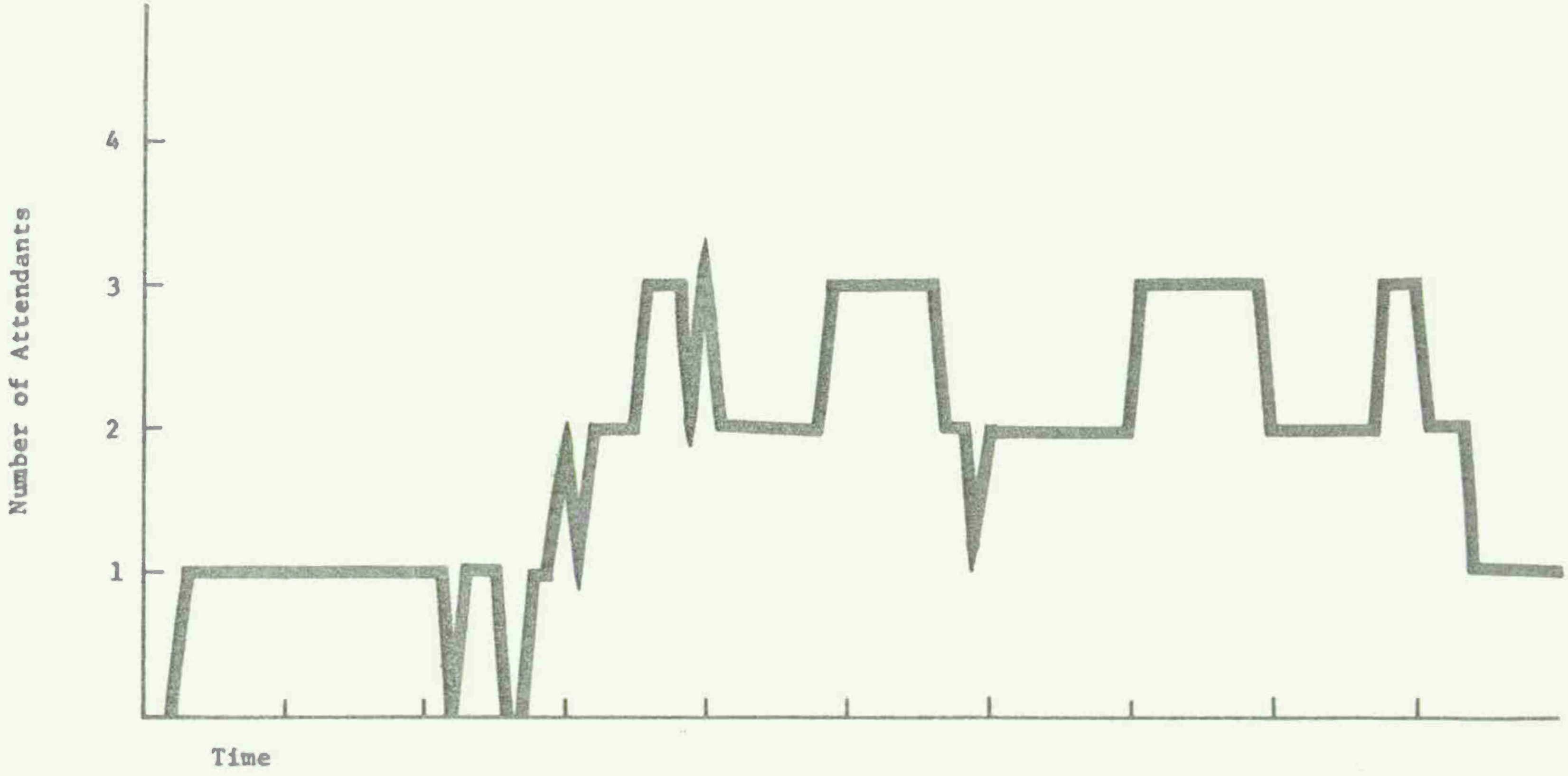


Figure 12

PROBABILITY FUNCTIONS vs TIME
(with feedback)

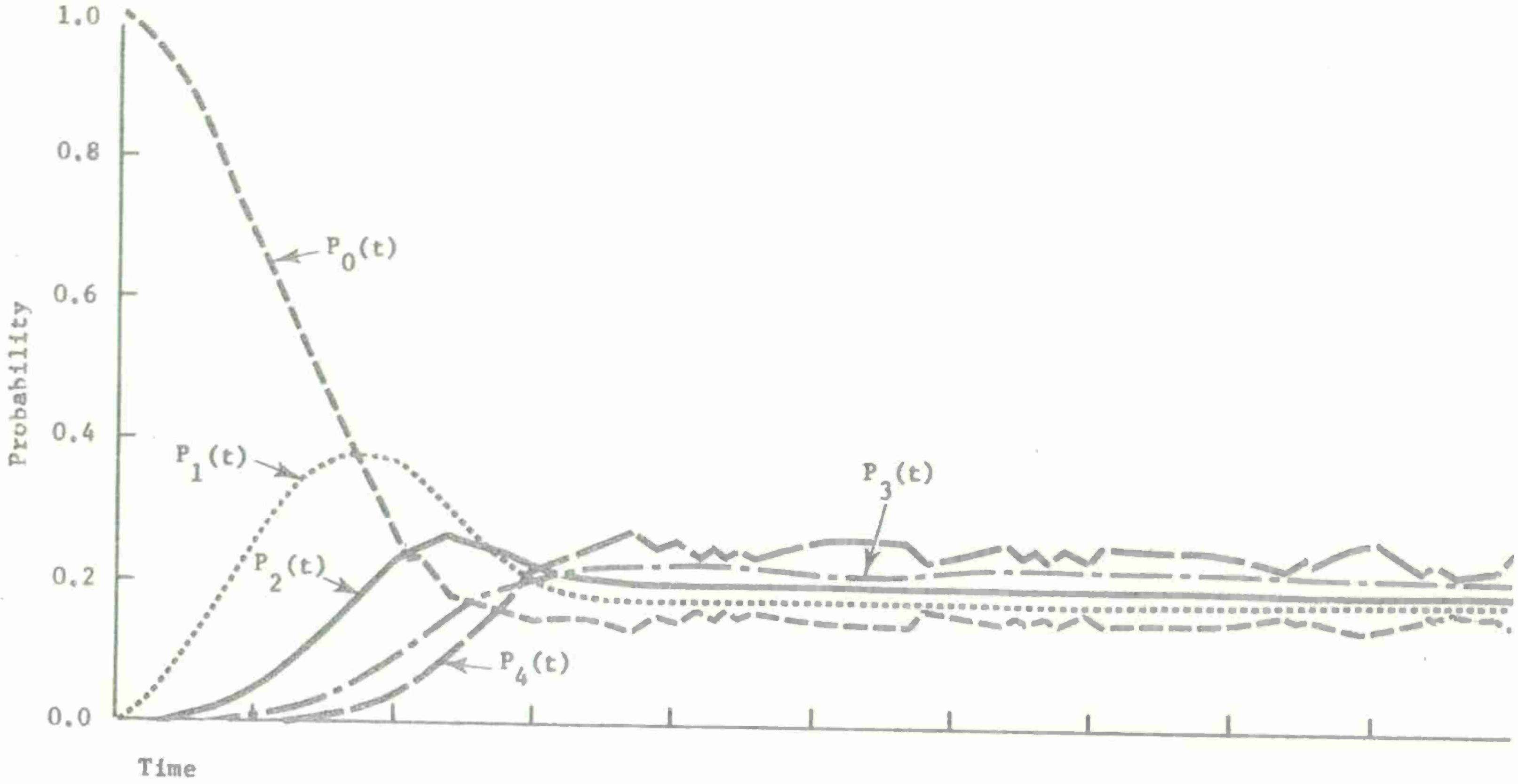


Figure 13

this form of feedback control is in driving the system toward steady state. Certainly the reader familiar with the basic principles of control theory will realize how much flexibility is now afforded the analyst.

The method of simulation described in this paper is not without limitations. One obvious limitation is the size of the analog computer needed to study large systems. If the system to be studied had a value of L = 50, a computer with approximately 100 operational amplifiers would be needed. Perhaps even more restrictive is the fact that approximately 125 multipliers would also be required.

Another problem that must be considered is that of computational stability. Since the structure of the system is one in which integrators are in series, any noise in the system can drive the system to saturation.

The problem of computational stability can be obviated by using one of the languages that makes a digital computer feel and act like an analog computer. The examples in this paper were developed and executed using IBM's "Continuous System Modeling Program" (CSMP). This system was adopted for the 1130 computer from the 1620 Pactolus Program. Some other possible programs are:

1. Digital Analog Simulator (DAS)

2. Digitally Simulated Analog Computer (DYSAC)

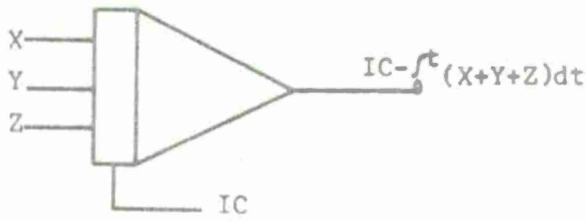
3. A Digital Simulation Program For Continuous System Modeling (DSL/90)

4. Analog Approach to Digital Computation (MIDAS).

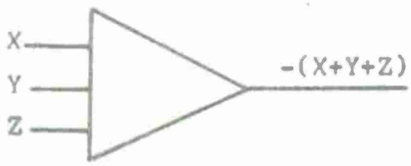
The problem of maximum system size still remains with the digital computer programs. CPSM for the 1130 has a maximum of 25 integrators.

Even with the computational limitations inherent in this methodology it still remains a very valuable analysis tool. With this approach, the need for complex and often limited mathematical analysis is reduced. Time histories of the functions are presented giving both the transient and steady state solution. Possibly the greatest outgrowth of this methodology is the ability to incorporate the use of feedback control theory.

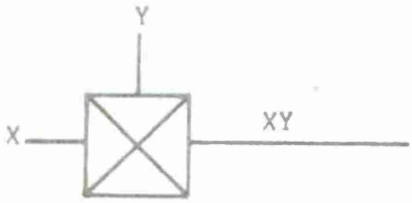
DEFINITIONS OF SYMBOLS



Integrator



Summer



Multiplier

MONTE CARLO METHODOLOGY IN THE DESIGN OF TRUNCATED SEQUENTIAL TESTS

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URS Corporation
Cognizant Agency: U.S. Army Electronic Proving Ground, Fort Huachuca, Arizona

INTRODUCTION

Conventional testing techniques have involved the use of the fixed sample size statistical approach in which sample size (number of parts to be tested, number of hours for a life test) is predetermined. Recently, sequential statistical techniques have been introduced which generally result in significantly less testing to obtain the same significance levels that fixed sample size techniques do. They accomplish this by allowing for test termination when warranted by the accumulated test data rather than at some predetermined number of observations or amount of test time. However, sequential methods have the disadvantage that, if one is sufficiently unlucky, a given test may require an arbitrarily large sample or arbitrarily long testing period. To counteract this undesirable attribute of sequential methods, truncated sequential methods were developed. These methods establish upper bounds on the amount of testing to be done but, like the sequential methods, allow for earlier test termination if warranted.

This paper presents background discussion of sequential and truncated sequential techniques, including those for reliability. Iterative, Monte Carlo techniques are described for producing truncated sequential test plans for reliability. A computer program is described which not only produces these test plans but which is potentially capable of producing truncated sequential test plans based on other distributions.

SEQUENTIAL PROBABILITY RATIO TESTS (SPRT)

The term sequential experimentation does not have a precise technical meaning. It is used generally for experiments in which:

- - there is a definite time sequence in which test observations are taken;
- - the process of measurement is rapid so that one test result is known before the next test is started.

When an experiment is sequential, the experimenter can stop after every observation and examine the accumulated results to date before deciding whether to continue the experiment. In other words, the analysis can be done sequentially as well as the experiment. It seems plausible that a sequential analysis should be more efficient than the traditional fixed sample size experiment, in which the number of observations needed is estimated in advance and no analysis of the results is made until this number of observations has been obtained.

In the traditional fixed sample size test, two hypotheses are specified: the null hypothesis, and the alternate hypothesis. Two risks are then chosen: α (producer's risk), the probability of rejecting the null hypothesis when true (Type I error) and β (consumer's risk), the probability of accepting the null hypothesis when false (Type II error). E.g., in a reliability experiment, the hypothesis might be that the equipment to be tested has a mean time between failures (MTBF) of 1500 hours; the alternate hypothesis might be that the MTBF is 1000 hours; the risks might be chosen to be $\alpha = .10$ and $\beta = .15$, i.e., there should be a 10% chance of rejecting equipment which really has an MTBF of 1500 hours and there should be a 15% chance of accepting equipment which really has an MTBF of 1000 hours. On the basis of α and β the sample size n is chosen before the experiment is performed.

Sequential tests refer to techniques for testing statistical hypotheses when the sample size n is not fixed in advance, but is determined during the course of the experiment by criteria that depend upon the observations as they occur. The following considerations make sequential testing interesting from both the theoretical and practical viewpoints. Assume that it had been determined that the best fixed sample size test required n = 100 observations. In obtaining the 100 observations required to test the null hypothesis, it is possible that among the first few observations there may be one or more so improbable under the alternative hypothesis that eventual rejection of the null hypothesis is out of the question; it would, therefore, be a waste of time to make the remaining observations. In other instances, the first 20, 30, or 40 observations may provide sufficient evidence, relative to α and β, for accepting or rejecting the null hypothesis. In short, the possibility is raised that, by constructing the test in a fashion that permits termination of the sampling at any observation, one can test the null hypothesis with fixed errors α and β and yet do so with fewer than 100 observations on the average. This is the case, in fact, although it may at first appear surprising in view of the fact that the best test for fixed sample size does require 100 observations. The saving in observations is often quite large, sometimes more than 50 per cent (see Reference 1).

The most frequently used sequential test is the sequential probability ratio test. In many problems, a parametric form is assumed for the density (or discrete) probability function, and two simple hypotheses are specified by two values of the parameter. Let $f(x, \theta)$ be a family of densities (or discrete probability functions) of a random variable X with parameter θ. Suppose that θ is unknown, and that observations will be taken on X to determine whether θ is large or small. One way of formalizing this problem is to say that a test will be made of the null hypothesis H_0 that $\theta=\theta_0$ against the alternative hypothesis H_1 that $\theta=\theta_1 > \theta_0$, where θ_0 and θ_1 are two suitably chosen numbers. The sequential probability ratio test is a procedure for this testing problem.

Let

$$z(x) = \ln \frac{f(x,\theta_1)}{f(x,\theta_0)} ,$$

and choose two numbers A and B ($< A$). The procedure consists of taking observations x_1, x_2, ... sequentially. At the nth step, calculate

$$Z_n = \sum_{i=1}^{n} z(x_i)$$

and, if $\ln B < Z_n < \ln A$, take another observation; if Z_n is not greater than ln B, accept H_0 (equivalently reject H_1); and, if Z_n is not less than ln A, accept H_1 (equivalently reject H_0). Simple and accurate approximations (see reference 2) are available for A and B, i.e.,

$$A \doteq \frac{1-\beta}{\alpha}$$

$$B \doteq \frac{\beta}{1-\alpha}$$

This makes the performance of a sequential test quite simple. α and β are chosen, ln A and ln B are calculated, and one then proceeds with the test.

TRUNCATED SEQUENTIAL PROBABILITY RATIO TESTS (TSPRT)

One difficulty with the sequential probability ratio test is that the sample size is a random variable that is unbounded and has a positive probability of being greater than any given constant (although this test does terminate with probability one). Limitations on time for testing, cost, and other practical considerations usually make it impossible to provide for the taking of an arbitrarily large number of observations. For this reason, the sequential probability ratio test is frequently truncated. That is, after N observations have been made, testing is stopped, and a decision is made by rejecting H_0 if $Z_n > 0$, and accepting H_0 otherwise. (This test, with A and B chosen differently so as to give the desired probabilities of Type I and II errors, is called the truncated sequential probability ratio test.) By truncating the sequential probability ratio test at the Nth observation, the probabilities of errors of Types I and II, say α' and β', are increased. Wald (see Reference 2) derived upper bounds for α' and β'. It is known that truncation substantially increases α' and β' when N is small. As N increases, the effect of truncation vanishes.

The truncated sequential probability ratio test is well-suited for a number of testing problems. Unfortunately, however, there are no simple approximations for the two constants (say A' and B') required to apply this test.

TSPRT'S FOR RELIABILITY (TSPRTR)

It is often assumed in reliability work that the time between failures is exponentially distributed (see Reference 3), so that $f(x,\theta)=\theta^{-1}\exp(-x/\theta)$.

Under this assumption θ is the mean time between failures (MTBF), and a simple transformation of variables alters the criteria for accepting or rejecting the null hypothesis to yield the following:

- - Reject if the Ith failure occurs on or before

$$T_c = \max\left[0,\ (I-1-I_A)/S\right],\ 0 \leq I \leq [R_0]$$
$$= T_0,\ I = [R_0]+1$$

- - Accept if the Ith failure occurs on or after

$$T_c = \min\left[T_0,\ (I-1-I_B)/S\right],\ 0 \leq I \leq [R_0]$$
$$= T_0,\ I = [R_0]+1$$

- - Otherwise continue testing

where $I_A = \ln A/ \ln D$

$I_B = \ln B/ \ln D$

$S = (D - 1) / \ln D$

$[R_0]$ = maximum number of failures, if integral
= maximum number of failures, truncated to next smallest integer, if not integral

T_0 = time truncation point

$D = \theta_0/\theta_1$ is called the discrimination ratio.

It is frequently useful to plot these criteria as failures as a function of total test time. Figure 1 shows a typical plot and three variations. Given a graph of this sort, the test engineer can plot the progress of his test until a boundary is crossed, at which time he can terminate his test. Figure 2 illustrates a typical test plan with two possible test histories, one resulting in rejection, the other in acceptance.

In these plots, the slanted acceptance and rejection lines have slope S and intercepts I_B and I_A respectively. The time and failure cutoffs, T_0 and R_0, are not independent:

$$R_0 = T_0 S$$

i.e., the lines defined by these cutoffs must intersect on the line of slope S through the origin (see Reference 3).

PROJECT HISTORY

In the course of a contract (DAAD04-67-C-0190) URS received from the U.S. Army Electronic Proving Ground (USAEPG), Fort Huachuca, Arizona, it

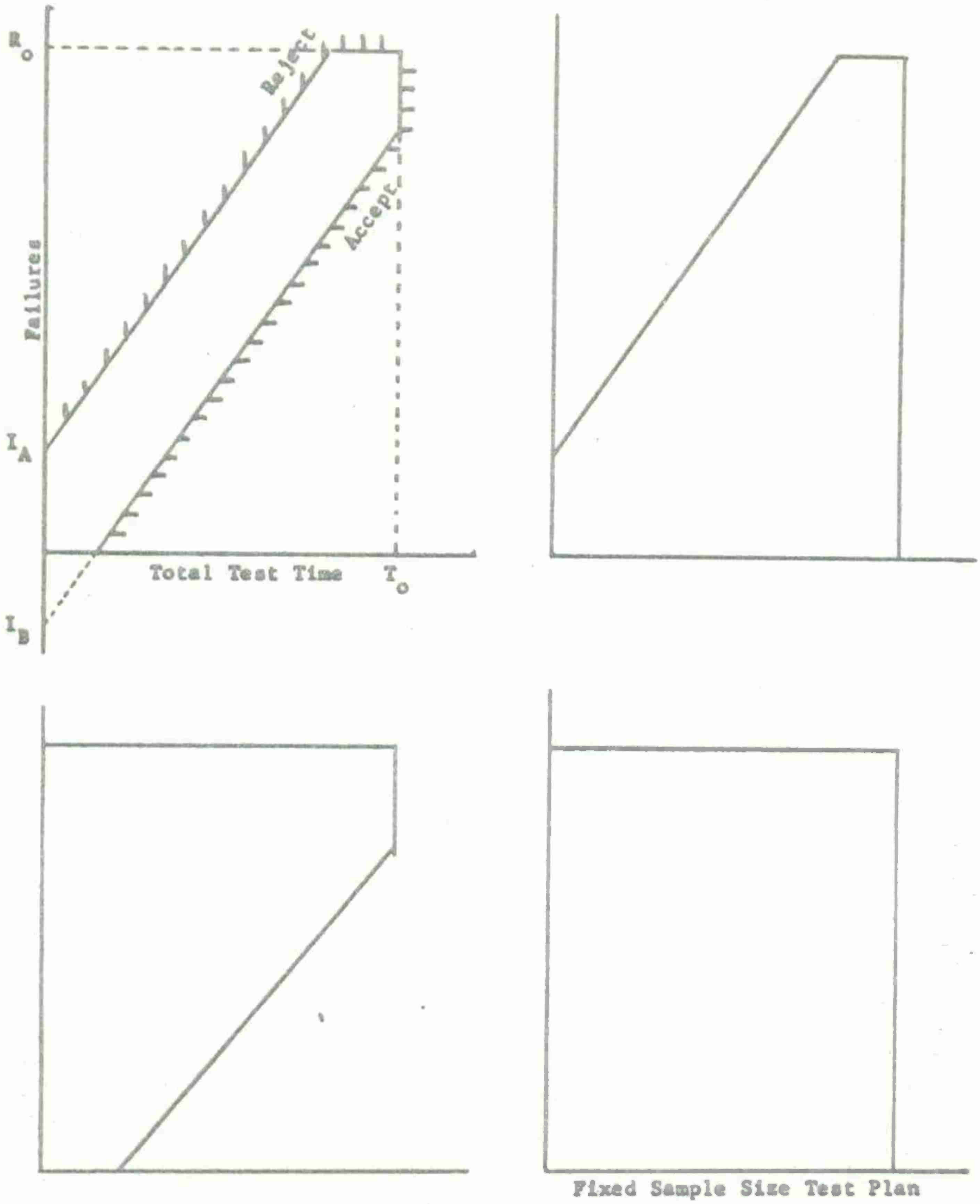

Figure 1. Typical TSPRT and Variations

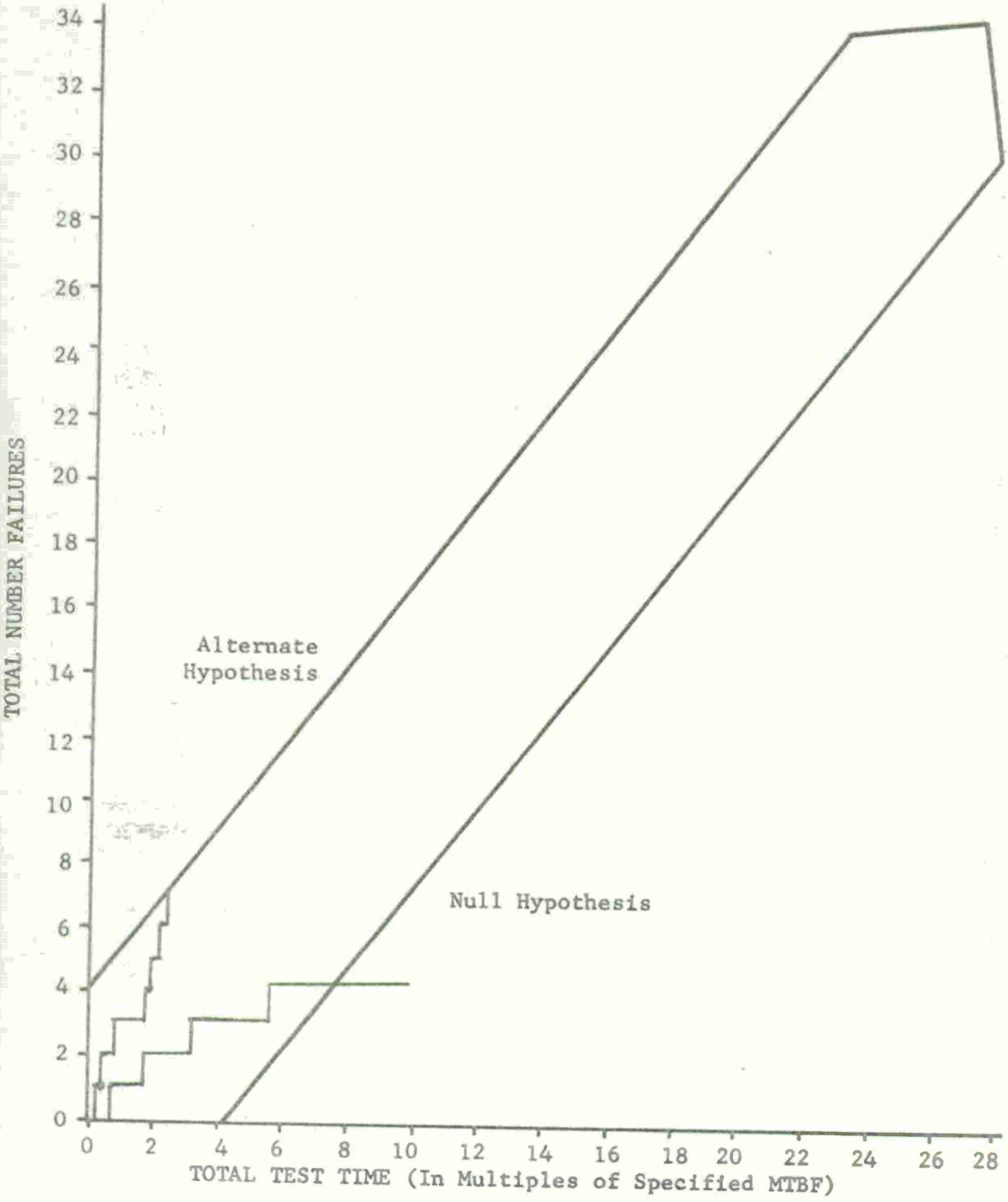

Figure 2. Reliability Test Random Walks

became apparent that potential users of truncated sequential probability ratio tests at the USAEPG in the field of reliability were having difficulty in applying these tests due to several short-comings of the principal document in the field, MIL-STD 781A, Reliability Tests Exponential Distribution.

Among these difficulties were:

- - limited number (9) of test plans;

- - unknown theoretical basis of the truncation rules.

It was decided to produce a computer program which USAEPG personnel could readily use which could produce truncated sequential probability ratio test plans, not only for reliability tests based upon the exponential distribution, but also for other tests where the underlying probability distributions were not exponential. This program is called the Sequential Test Plan Generator (STPG). In the rest of this paper the basic functional concepts of STPG are described and a test plan produced by STPG is given.

TEST PLANS BY SAMPLING

As indicated above, TSPRT's with

$$A = (1 - \beta)/\alpha \qquad \text{and} \qquad B = \beta/(1 - \alpha)$$

do not usually turn out to have true probabilities of errors of Type I and II (say α' and β') equal to α and β respectively. Epstein, Patterson, and Qualls have described the exact calculation of α' and β' given A and B in Reference 3. Burnett (see Reference 4) took a different, Monte Carlo, approach.

Given a method of calculating α' and β', an iterative approach can be used to find a test plan (i.e., an A and B) to yield desired values of α and β :

(1) Choose an initial A_0 and B_0 (using the above approximation).

(2) Determine true probabilities of errors of Types I and II, α' and β'.

(3) Calculate errors:

$$E_\alpha = \alpha' - \alpha$$

$$E_\beta = \beta' - \beta$$

(4) Calculate new A and B, based on previous values of E_α and E_β.

(5) Go to (2) and continue until max ($|E_\alpha|$, $|E_\beta|$) $< \epsilon$, some specified tolerance level.

STPG uses this approach. The exact values of α' and β' are estimated by a Monte Carlo method similar to that of Burnett: Tests are simulated under both hypotheses using exponentially distributed random numbers to get the times between failures. These tests may be thought of as random walks in the direction of increasing test time and failures, starting at the origin, and proceeding with steps of exponentially distributed lengths parallel to the time axis and unit steps parallel to the failure axis. The random walks terminate when a boundary is crossed. Counts are maintained of the number of acceptances from random walks based on the alternate hypothesis and of the number of rejections from random walks based on the null hypothesis. The ratios of these counts to the total number of random walks yields the estimators of β' and α' respectively.

Exponentially distributed random numbers may be obtained by selecting a uniformly distributed random number r, setting it equal to the formula for the cumulative distribution of times between failures:

$$r = 1 - e^{-t/\theta}$$

Solving for t:

$$t = -\theta \ln (1 - r)$$

The revision of A and B is based on a scheme called the Modified Newton's Method:

The error in alpha is considered to be a function of A and B

$$f(A,B) = ERRALF$$

and the error in beta is also considered to be a function of A and B

$$g(A,B) = ERBETA$$

A Taylor's Series expansion of f and g yields

$$f(A+\Delta A, B+\Delta B) = f(A,B)+\Delta A f_A+\Delta B f_B$$

$$g(A+\Delta A, B+\Delta B) = g(A,B)+\Delta A g_A+\Delta B g_B$$

where $f_A = \partial f/\partial A$, etc. It is desired that f and g be zero at $(A+\Delta A,\ B+\Delta B)$, so

$$f(A,B)+\Delta A f_A+\Delta B f_B = 0$$

$$g(A,B)+\Delta A g_A+\Delta B gB = 0$$

These may be solved to yield

$$\Delta A = \frac{g(A,B)f_B - f(A,B)g_B}{f_A g_B - f_B g_A}$$

$$\Delta B = \frac{f(A,B)g_A - g(A,B)f_A}{f_A g_B - f_B g_A} .$$

For small alpha and beta

$A \doteq (1-\beta)/\alpha$

$B \doteq \beta/(1-\alpha)$

These may be solved to yield

$\alpha = (1-B)/(A-B)$

$\beta = B(A-1)/(A-B)$.

Thus it is approximately true that

$$\text{ERRALF} = \alpha' - \alpha$$

$$= \big((1-B)/(A-B)\big) - \alpha$$

and

$$\text{ERBETA} = \beta' - \beta$$

$$= \big(B(A-1)/(A-B)\big) - \beta .$$

If α and β are held constant, it is then approximately true near A and B that

$f_A = (B-1)/(A-B)^2$

$f_B = (1-A)/(A-B)^2$

$g_A = B(1-B)/(A-B)^2$

$g_B = A(A-1)/(A-B)^2$,

This gives rise to the following algorithm for determining subsequent values of A and B:

$$A'_{i+1} = \frac{g(A_i,B_i)f_B - f(A_i,B_i)g_B}{f_A g_B - f_B g_A} + A_i$$

$$B'_{i+1} = \frac{f(A_i,B_i)g_A - g(A_i,B_i)f_A}{f_A g_B - f_B g_A} + B_i .$$

However, A_{i+1} and B_{i+1} must be held between certain limits:

$$B_{i+1} \leq 1 \leq A_{i+1} .$$

Further limits are obtained using the following considerations: (See Figure 3). The time and failure truncation lines and axes form a rectangular region. Modifying A and B causes only the intercepts of the slanted rejection and acceptance lines (respectively) to change, but not the slope. However, if A becomes so large or B so small that those lines no longer intersect the rectangle, then further change in A or B results in no change in alpha and beta.

Thus, A_{max} is the A such that $I_A = R_0$ and B_{min} is the B such $I_B + ST = 0$; i.e.

$$\ln (A_{max})/\ln D = R_0 = ST_0$$

$$\ln (B_{min})/\ln D = -ST_0$$

from which can be obtained

$$A_{max} = 1/EXPT$$

$$B_{min} = EXPT$$

where $EXPT = \exp(-T_0(D-1))$.

Thus,

$$A_{i+1} = \min(1/EXPT, \max(1, A^1_{i+1}))$$

$$B_{i+1} = \max(EXPT, \min(1, B^1_{i+1})).$$

A TEST PLAN PRODUCED BY STPG

Figure 4 illustrates the normal output of STPG.

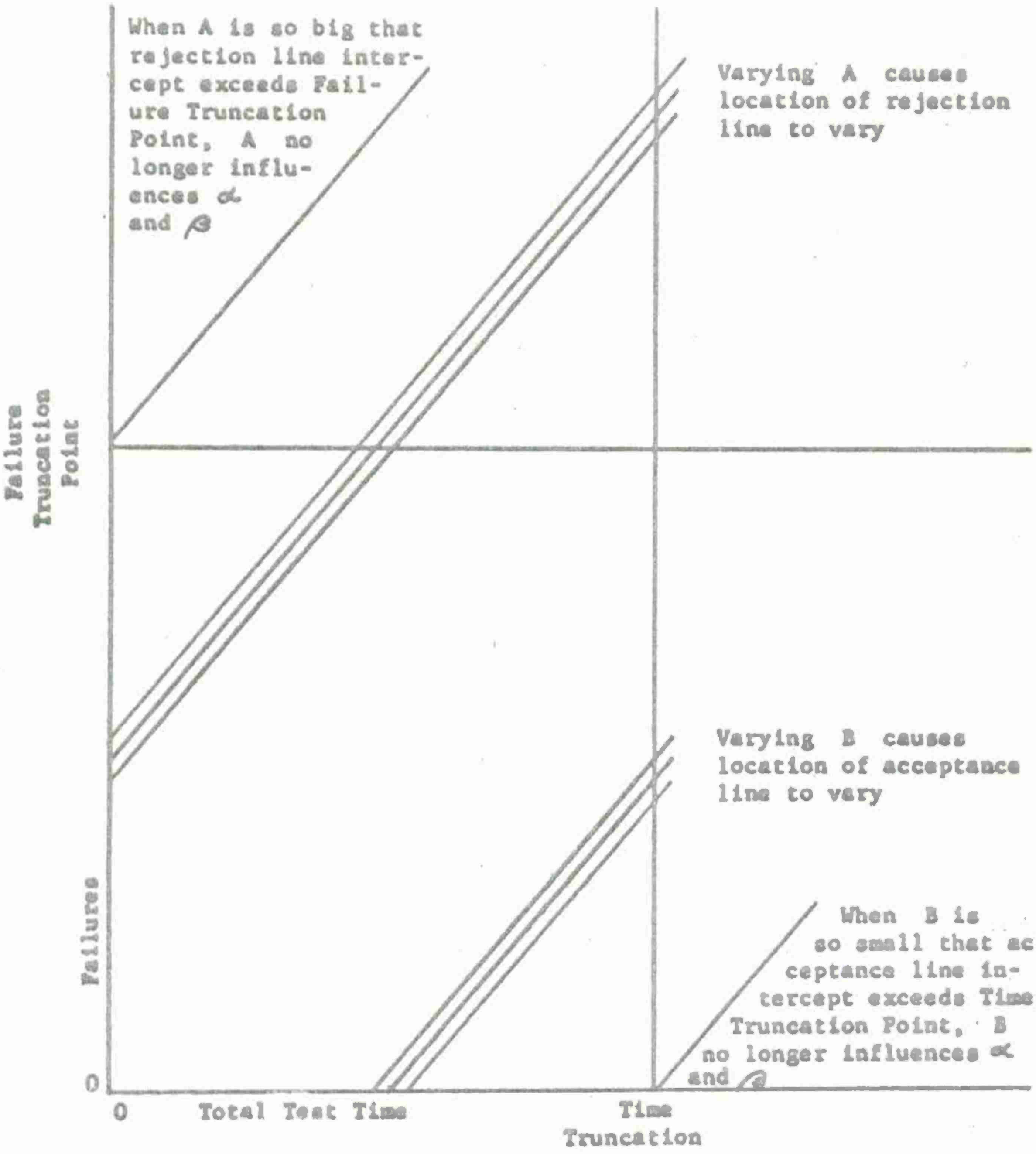

Figure 3. Limits on A and B

TRUNCATED SEQUENTIAL PROBABILITY RATIO TEST PLAN FOR RELIABILITY - PREPARED BY THE SEQUENTIAL TEST PLAN GENERATOR

ALPHA = .100000
BETA = .100000
DISCRIMINATION RATIO = 5.000
TIME TRUNCATION POINT = 1.200
MAXIMUM FAILURES = 2.982

A = 13.487
B = 0.103
SLOPE = 2.485
FAILURE-AXIS INTERCEPTS:
    ACCEPTANCE = -1.412
    REJECTION = 1.617
TIME AT WHICH REJECTION BOUNDARY LEVELS OFF = 0.55

ALPHA PRIME = 0.09767
BETA PRIME = 0.10100

EXPECTED TEST DURATION UNDER
    NULL HYPOTHESIS = 0.748
    ALTERNATE HYPOTHESIS = 0.511

NUMBER OF FAILURES	TOTAL TEST TIME IN MULTIPLES OF SPECIFIED MTBF REJECT (EQUAL OR LESS)	ACCEPT (EQUAL OR MORE)
0	0.	0.57
1	0.	0.97
2	0.15	1.20
3	1.20	1.20

(EPSLN = .005, TSTMX = 3000, ITERATIONS = 10, ORIGINAL A = 9.000, ORIGINAL B = 0.111)

Figure 4. Example of Normal Output

TIMING

The amount of time required for a test plan is a function of several variables:

- - number of random walks per iteration
- - number of iterations
- - maximum number of iterations in case of non-convergence.

Fairly precise timing estimates are available in reference 5, Appendix II, pp. 41-43. The preceding test plan required about 27 seconds of computer time on an IBM 7090.

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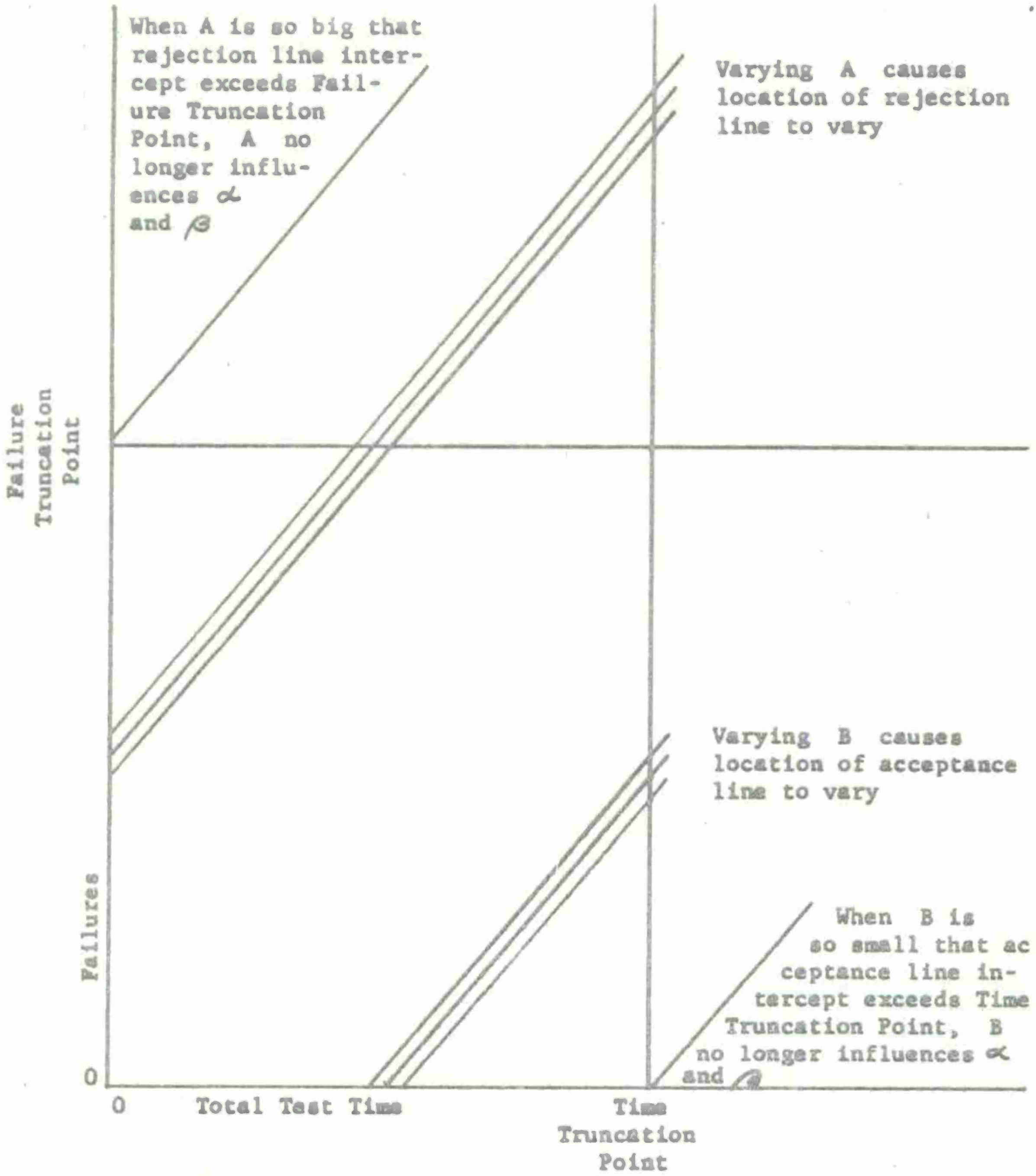
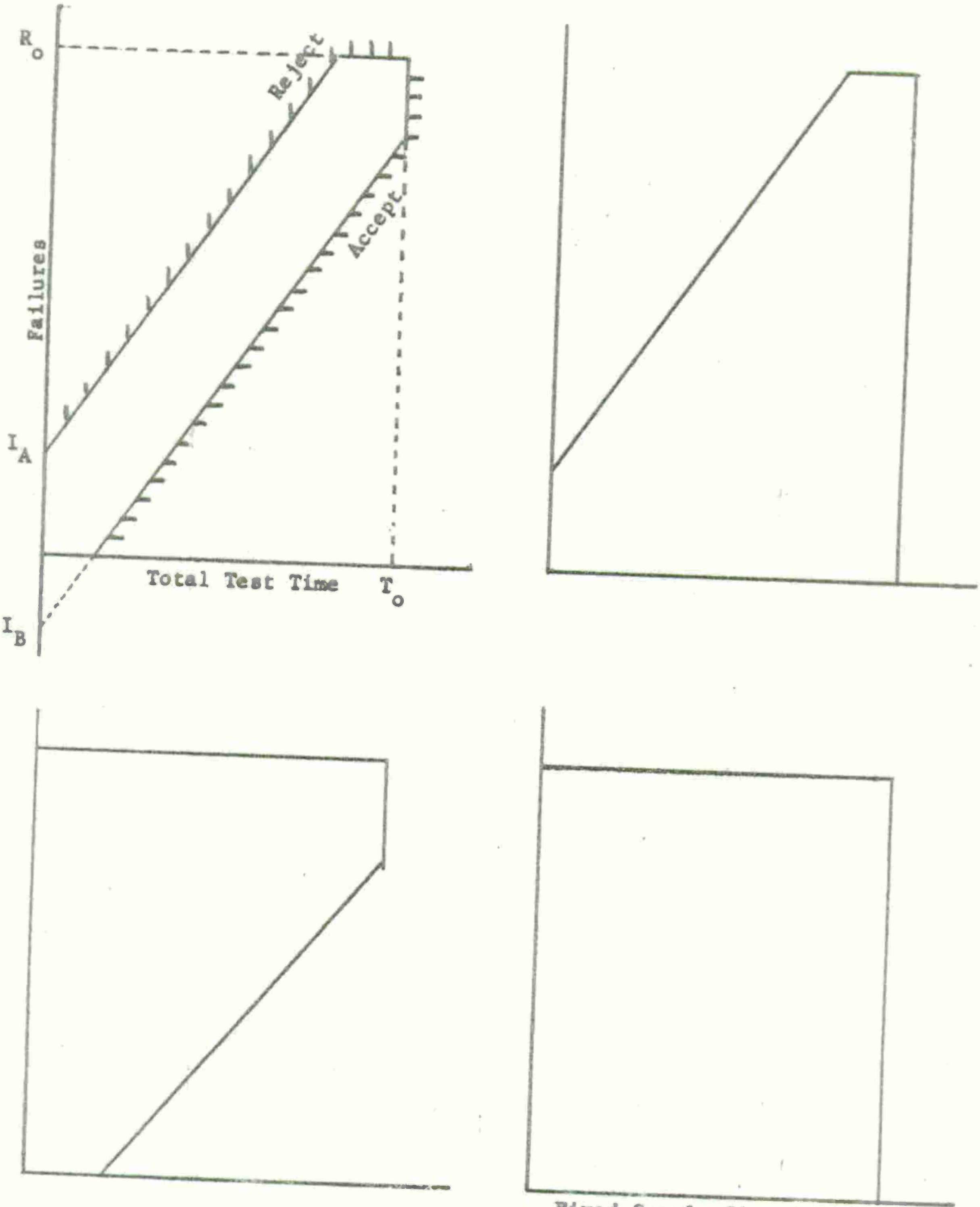


Figure 3. Limits on A and B



Fixed Sample Size Test Plan

Figure 1 Typical TSPRT and Variations

AN EXPERIMENTAL COMPARISON OF MONTE-CARLO SAMPLING TECHNIQUES TO EVALUATE THE MULTIVARIATE NORMAL INTEGRAL

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U S Army Behavioral Science Research Laboratory

Experimental results have been obtained to evaluate two different methods of Monte-Carlo sampling to integrate the multivariate normal probability density function. These results for different types of probability integrals and a description of the sampling techniques are presented in this paper

Probability regions over the multivariate normal distribution are often useful in investigating behavior of multidimensional variates encountered in personnel and other operations research areas. As an example, consider the population of Army personnel about to enter advanced training. Suppose the distribution of score vectors which predict performance in each of 8 Army occupation areas can be characterized for this population by an 8 variate multivariate normal distribution. An existing policy might be to accept all men for further training who score above 100, say, on all 8 aptitude areas. This results in an acceptance of a proportion p of all men in the population Requirements may change so that p + .05 of the total number needs to be accepted, and several different ways to lower the cut-off scores are suggested to meet the increased requirements. Evaluating the multivariate integral between the new and old cut-off scores will give a direct estimate of whether a proposed policy change is too stringent (the multidimensional area may be .001, considerably smaller than the required increase of 05) or too lenient (as when the increased probability area is .15, rather than .05).

A general analytical method for integrating the multivariate normal distribution is at the present time unavailable The integral can be approximated by numerical quadrature, but a very large number of data points need to be generated when the number of dimensions is large To improve the approximation to the integral and shorten computation time, another approach is to obtain the observations by random sampling over the region of integration, rather than using the systematic sampling of quadrature. Such a "Monte-Carlo" approach will yield probability estimates which vary from sample to sample The larger the variance, however, the larger is the number of points which must be generated to obtain a given degree of precision, and again the time required for computations may be appreciable Assuming then that a given Monte-Carlo method yields unbiased estimates, the precision of the method can be evaluated from the magnitude of the variance of the estimates over independent samples.

One of the Monte-Carlo methods described in this paper has already been used and reported by Hillier (1961) Random vector observations are generated to have the distribution of the multivariate normal distribution of interest. Then the proportion of observations which fall

within the specified region of integration constitutes the probability estimate. Even though the computations involved are very simple, this type of estimate shows considerable change from sample to sample. Such variability serves, however, as a useful standard by which to compare the behavior of a second method of Monte-Carlo sampling, more complex computationally, but which showed promise of yielding estimates with a higher degree of precision.

Monte-Carlo Method I: The Model

Since any multivariate normal distribution can be easily converted to standard form, methods of integration can be described in more general terms with reference to the standardized distribution. Let $X = [x_1, x_2, \ldots, x_k]$ represent a k-dimensional vector of random variables distributed as the multivariate normal with mean vector $\underline{0}$ and correlation matrix R. The multivariate normal integral over a given region $A = [(\ell_1, u_1); (\ell_2, u_2), \ldots, (\ell_k, u_k)]$ is

$$\pi = \int_A f(X)dX$$

$$= \frac{|R|^{-\frac{1}{2}}}{(2\pi)^{k/2}} \int_{\ell_1}^{u_1} \int_{\ell_2}^{u_2} \cdots \int_{\ell_k}^{u_k} \exp\left[-\tfrac{1}{2}(X R^{-1} X')\right]dX.$$

To estimate π, introduce a new random variable y, where

$$y = 1 \text{ if } X \in A \tag{1}$$

$$y = 0 \text{ otherwise}$$

In scalar notation $X \in A$ if $\ell_j < x_j < u_j$ for $j = 1, 2, \ldots, k$.
Then

$$E(y) = 0 + \int_{\ell_1}^{u_1} \int_{\ell_2}^{u_2} \cdots \int_{\ell_k}^{u_k} f(x_1, x_2, \ldots, x_k)dx_1 dx_2 \ldots, dx_k + 0$$

$$= \pi.$$

The estimate of π is the random variable $p = \frac{\sum_{i=1} y_i}{n}$, where $y_1, y_2, \ldots, y_n$ represent a sample of independent random variables defined as in (1) from n vector observations $X_1, X_2, \ldots X_n$ randomly sampled from $f(X)$.

To obtain the observed values $y_1, y_2, \ldots, y_n$, first, n vectors Z_i of independent random normal deviates are generated: Z has mean vector $m_z = \underline{0}$ and the identity correlation matrix $I = R = \mathrm{Var}(Z'Z)$ when $n \to \infty$. Then $X_i = Z_i R^{\frac{1}{2}}$ for $i = 1, 2, \ldots, n$, where $R^{\frac{1}{2}}$ is the square root matrix of R. Furthermore, $m_x = \underline{0}$ and $\mathrm{Var}(X) = R^{\frac{1}{2}} Z'Z R^{\frac{1}{2}} = R^{\frac{1}{2}} I R^{\frac{1}{2}} = R$ when $n \to \infty$, as is required for the parameters which characterize $f(X)$. If, for each element x_{ij} of any vector X_i, $\ell_j < x_{ij} < u_j$, then y_i is set to 1; but if any element of X_i falls outside the specified interval, y_i is set to 0.

Monte-Carlo Method II

The second method, an adaptation of importance sampling, is an original approach to Monte-Carlo sampling suggested by Boldt (1966). In importance sampling, the random numbers upon which the estimates of the unknown parameter are based are generated from a distribution other than the one suggested by the problem. Each value of this "biased" sample is multiplied by an appropriate weighting factor which corrects for having used the wrong distribution. The biasing is done to increase the probability of a sample being drawn from an "interesting" or "important" region and decrease the probability of it coming from an "uninteresting" or "unimportant" one. By spending relatively more computation time on random numbers generated from certain portions of the probability region, it is possible to improve the precision, that is, to reduce the variance, of the estimate.

Boldt suggested that a multivariate normal distribution with a single common factor covariance structure often is a good approximation to covariance structure observed in practice and might serve as a suitable sampling distribution. The importance sampling technique requires a solution for the integral of the sampling distribution over the same limits required for the unknown integral. A simple quadrature solution does exist for variance-covariance matrices with the special structure and has been described a number of times in the literature (e.g., Curnow and Dunnett, 1962). Furthermore, the generation of random observations which have one common factor is also quite simple. To force the points within the specified limits of integration complicates the computational procedure somewhat, but does not result in a significant increase in computer time.

The choice of an appropriate design for importance sampling is not routine, and the variance of the sample estimates may be increased, even infinitely, if the random data points are generated from an unsuitable distribution. Whether the proposed adaptation of importance sampling produces an advantage by variance reduction [illegible] experiment [illegible] and provides the motivation [illegible]

The Model

To estimate $\pi = \int_A f(X)dX$

using the importance sampling approach, a probability density function $g(X)$ is introduced such that $\int_A g(X)dX = 1$.

Then π can be stated in terms of the expected value of the function $f(X)/g(X)$: i.e.,

$$\pi = \int_A \frac{f(X)}{g(X)} g(X)dX = E\left[\frac{f(X)}{g(X)}\right] \quad (2)$$

Then the estimate for π is an estimate for an expected value:

$$p = \frac{1}{n} \sum_{i=1}^{n} \frac{f(X_i)}{g(X_i)}$$

where $X_1, X_2, \ldots, X_n$ are random vectors sampled from $g(X)$.

Let R_g represent a correlation matrix with the structure $r_{ij} = \alpha_i \alpha_j$ $(i \neq j)$, where $-1 \leq \alpha_i \leq +1$ for $i = 1, 2, \ldots, k$.

Then

$$g(X) = \frac{k_g |R_g|^{-\frac{1}{2}}}{|2\pi|^{k/2}} \exp\left[-\tfrac{1}{2}(X R_g^{-1} X')\right] = k_g g^*(X) = \frac{1}{p_g} g^*(X) \text{ if } X \in A$$

$$0 \text{ otherwise.}$$

The cumulative density function of $g(X)$ can be expressed as a single integral having a product of univariate normal cumulative density functions in the integrand; consequently, p_g is easy to evaluate numerically. Then

$$\pi = \int_A p_g \frac{|R_f|^{-\frac{1}{2}}}{|R_g|^{-\frac{1}{2}}} \exp\left[-\tfrac{1}{2}X(R_g^{-1} - R_f^{-1})X'\right] g(X)dX$$

$$P = p_G \frac{|R_f|^{\frac{1}{2}}}{|R_g|^{\frac{1}{2}}} \sum_{i=1}^{n} \exp\left[-\tfrac{1}{2}X_i(R_g^{-1} - R_f^{-1})X_i'\right]$$

where $X_1, X_2, \ldots, X_n$ represent the random sample of vectors from the distribution $g(X)$ defined over V.

It may be noted that a standard approach to integration by Monte-Carlo sampling is based on the same model stated in (2). Rather than letting $g(X)$ represent a normal distribution, however, a uniform distribution is used. A number of estimates for the multivariate normal integral were obtained in this way, but the results were generally quite poor.

Description of the Monte Carlo Experiments

The relative efficiencies of the different Monte-Carlo methods were examined for a variety of experimental problems. Two series of runs were prepared, one with four variates and the other with eight; the experimental problems for the two series were designed to be somewhat comparable. The correlation matrix R_f characterizing the multivariate normal distribution for the "unknown" integral was chosen to have a single common factor with all correlations of the structure $r_{ij} = \alpha_i\alpha_j$, where $-1 \leq \alpha_i \leq +1$ for $i = 1, 2, \ldots, k$. Then the unknown probability area could be verified from the same quadrature formula used earlier to compute the probability area for the single common factor distribution from which the random observations are generated. Such a choice for R_f, however, lessens the representativeness of the problem. To evaluate the importance sampling approach, results should be compared when sampling proceeds from a distribution which poorly approximates the distribution of interest, as well as when both distributions each have only one common factor. To increase the generality of the results, therefore, for each single common factor R_f, both a "good" single factor approximation and a "poor" single factor approximation were constructed for the sampling distribution.

All correlations in R_f were chosen to be .90 (both for 4 and 8 variates) for one series of problems. Such high positive correlations will yield multidimensional probability regions highly concentrated about the center of the distribution. To work with probability regions more evenly distributed over the infinite domain, all correlation elements were set to .10. Four and eight variate matrices containing randomly

selected positive correlations with more than one common factor were also constructed, although a quadrature procedure for checking the Monte-Carlo estimates was not available. For the two kinds of single common factor correlation matrices used for sampling, one R_g had the structure $r_{ij} = \alpha_i \alpha_j = (.90)(.90) = .81$, and the other had the structure $r_{ij} = (.10)(.10) = .01$ (both for 4 and 8 variate problems). For the "unknown" integral with all $r_{ij} = .90$, the R_g with all correlations equal to .81 represented the "good" importance sampling approximation; the R_g with all correlations equal to .01 represented the "poor" approximation. Conversely, when all r_{ij} were set to .10 in R_r, the R_g with correlations equal to .81 was the poor sampling approximation and the R_g with correlations of .01 was the good one.

Probability estimates were also obtained for 3 different kinds of integration limits. One set of limits included only the central portion of the distribution, -1. to +1. for all 4 or 8 variates. Another set included the tails, - ∞ to 0. for all variates. In a third set the limits contained a variety of both tails and central portions (-5. to -1.; -1 to 0: 0 to 1; and 1. to 5. for 4 variates and -3. to 1 ; -3. to 2; -3 to 3.: -2 to 1.: -2 to 2.; -2 to 3.; -1. to 2.; -1 to 3. for 8 variates).

In summary, the series of experiments used to compare the relative efficiency of two Monte-Carlo methods for evaluating the multivariate normal integral contained four categories of independent variables: 1) number of variates, 4 and 8; 2) structure of the multivariate normal distribution of interest, as characterized by a one common factor correlation matrix with high positive correlations, with low positive correlations, or by a correlation matrix with randomly selected positive correlations: 3) goodness of approximation of the sampling distribution to the multivariate normal distribution being integrated; 4) range of integration, with limits involving only the central portion of the distribution or including both tail and central portions as well.

All possible combinations of the independent variables planned for the series of experiments totalled 36 problems; 18 of these problems were based on 4 variate distributions and 18 comparable problems were for the 8 variate distributions. For each of these problems, 10 independent probability estimates were obtained. The estimates for the 4 variate problems were each based on an n of 1000 random vector observations; 10,000 random vectors were generated for each of the 8 variate problems.

Results from the Monte-Carlo Experiments

Results are presented in Tables 1 and 2. Of the 18 problems for each of the 4 and 8 variate series, there are 9 different probability

Table 1

Monte-Carlo Estimates Based on Two Different Sampling Procedures for Evaluating the Multivariate Normal Integral

4 Variate Problems, n = 1000

All correlations = .90; Centered limits: -1 to +1

Problem	Method	π	p	$s\|p$	s ratio	$s\|\pi$	s ratio
1	I	.5114	.5121	.02175		.02177	
1	II r_g=.81 Good	.5114	.5125	.00871	2.50	.00877	2.48
2	II r_g=.01 Poor	.5114	.5125	.02836	0.77	.02838	0.77

All correlations - .10: Centered limits: -1 to +1

Problem	Method	π	p	$s\|p$	s ratio	$s\|\pi$	s ratio
3	I	.2202	.2203	.01331		.01331	
3	II r_g=.81 Poor	.2202	.2156	.01092	1.22	.01186	1.12
4	II r_g=.01 Good	.2202	.2204	.00037	35.56	.00040	33.46

Full rank, positive correlations; Centered limits: -1 to +1

Problem	Method	p	$s\|p$	s ratio
5	I	.3217	.00212	
5	II r_g=.81	.3187	.01645	1.29
6	II r_g=.01	.3226	.00323	6.56

4 Variate problems, n = 1000

All correlations = .90: limits include tails: - ∞ to 0.

Problem	Method			π	p	s|p	s ratio	s|π	s ratio
7	I			.3693	.3618	.01639		.01803	
7	II	r_g=.8	Good	.3693	.3705	.00688	2.38	.00698	2 58
8	II	r_g=.01	Poor	.3693	.3296	.03068	.53	.05018	36

All correlations = .10; limits include tails: -∞ to 0.

Problem	Method			π	p	s|p	s ratio	s|π	s ratio
9	I			.0871	.0869	.01065		.01066	
9	II	r_g-.81	Poor	.0871	.0843	00963	1 11	.01003	1.03
10	II	r_g=.01	Good	.0871	.0871	.00075	14.23	.00075	14.22

Full rank, positive correlations; limits include tails: -∞ to 0.

Problem	Method		p	s|p	s ratio
11	I		.1951	.01304	
11	II	r_g=.81	.1954	.01783	.73
12	II	r_g=.01	.1919	.00892	1.46

4 Variate problems, n = 1000

All correlations = .90; limits are varied.

Problem	Method		π	p	s|p	s ratio	s|π	s ratio
13	I		.07054	.07410	.00780		.00858	
13	II r_g =.81	Good	.07054	.07063	.00145	5.38	.00145	5.90
14	II r_g =.01	Poor	.07054	.06926	.00723	1.08	.00734	1.17

All correlations = .10; limits are varied.

Problem	Method		π	p	s|p	s ratio	s|π	s ratio
15	I		.1535	.1544	01547		.01550	
15	II r_g=.81	Poor	1535	.1463	.02461	.63	.02562	.60
16	II r_g=.01	Good	.1535	.1534	.00042	36.74	.00043	35.93

Full rank, positive correlations; limits are varied

Problem	Method	p	s|p	s ratio
17	I	.1188	.01260	
17	II r_g =81	.1307	.04198	.30
18	II r_g =01	.1148	.00320	3.94

8 Variate Problems, n = 10,000

All correlations = .90; centered limits: -1 to +1

Problem	Method	π	p	s|p	s ratio	s|π	s ratio
1	I	.4302	.4309	.00335		.00343	
1	II r_g =.81 Good	.4302	.4304	.00327	1.03	.00327	1.05
2	II r_g =.01 Poor	.4302	.4245	.01582	.21	.01682	.20

All correlations = .10; centered limits: -1 to +1

Problem	Method	π	p	s|p	ratio	s|π	s ratio
3	I	.0499	.0502	.00229		.00232	
3	II r_g=.81 Poor	.0499	.0502	.00214	1.07	.00216	1.08
4	II r_g=.01 Good	.0499	.0499	.00005	45.02	.00006	38.87

Full rank, positive correlations; centered limits: -1 to +1.

Problem	Method	p	s|p	s ratio
5	I	.1757	.00378	
5	II r_g =.81	.1731	.00291	1.30
6	II r_g=.01	.1751	.00238	1.59

8 Variate Problems, n = 10,000

All correlations = .90; limits include tails: $-\infty$ to 0

Problem	Method	π	p	$s\|p$	s ratio	$s\|\pi$	s ratio
7	I	.3211	.3206	.00412		.00415	
7	II r_g = .81 Good	.3211	.3212	.00280	1.47	.00280	1.48
8	II r_g = .01 Poor	.3211	.2590	.02346	.17	.06640	.06

All correlations = .10: limits include tails: $-\infty$ to 0.

Problem	Method	π	p	$s\|p$	s ratio	$s\|\pi$	s ratio
9	I	.0141	.0141	.00095		.00095	
9	II r_g = .81 Poor	.0141	.0126	.00136	.70	.00203	.47
10	II r_g = .01 Good	.0141	.0141	.00010	9.03	.00011	8.64

Full rank, positive correlations; limits include tails: $-\infty$ to 0.

Problem	Method	p	$s\|p$	s ratio
11	I	.1349	.00337	
11	II r_g = .81	.1249	.00773	.44
12	II r_g = .01	.1206	.00697	.48

8 Variate Problems, n = 10,000

All correlations = .90; limits are varied

Problem	Method	π	p	s|p	s ratio	s|π	s ratio
13	I	.5962	.5960	.00564		.00564	
14	II r_g=.81	.5962	.5966	.00552	1.02	.00553	1.02
14	II r_g=.01	.5962	.5895	.08477	.07	.08503	.07

All correlations = .10; limits are varied

Problem	Method	π	p	s|p	s ratio	s|π	s ratio
15	I	.4359	.4393	.00379		.00510	
15	II r_g=.81	.4359	.3128	.03915	.10	.12919	.04
16	II r_g=.01	.4359	.4363	.00144	2.64	.00148	3.45

Full rank, positive correlations: limits are varied

Problem	Method	p	s|p	s ratio
17	I	.5234	.00488	
17	II r_g=.81	.4900	.09384	.05
18	II r_g=.01	.5191	.02511	.19

Table 2

Standard Deviation Ratios:

Variability of Importance Sampling Probability Estimates Relative to

Brute Force Monte-Carlo Estimates

4 Variates, n = 1000

Integrals		Centered		Tails		Varied	
$\{r_f\}$	$\{r_g\}$	Problem		Problem		Problem	
.90	.81, good	1	2.50	7	2.38	13	5.38
.90	.01, good	2	.77	8	.53	14	1.08
10	.81, poor	3	1.22	9	1.11	15	.63
10	.01, good	4	35.56	10	14.23	16	36.74
Random	.81	5	1.29	11	.73	17	.30
Random	.01	6	6.56	12	1.46	18	3.94

8 Variates, n = 10,000

Integrals		Centered		Tails		Varied	
$\{r_f\}$	$\{r_g\}$	Problem		Problem		Problem	
.90	.81, good	1	1.03	7	1.47	13	1.02
.90	.01, poor	2	.21	8	.17	14	.07
.10	.81, poor	3	1.07	9	.70	15	.10
.10	.01, good	4	45.02	10	9.03	16	2.64
Random	.81	5	1.30	11	.44	17	.05
Random	.01	6	1.59	12	.48	18	.19

regions being evaluated. The first line of values presented for each such region is based on the simple method of Monte-Carlo sampling. The second two lines of values were obtained using the importance sampling approach, but with one set of estimates being obtained from a "good" sampling distribution approximation and the other set from a "poor" approximation. For the single common factor distribution, probabilities computed by quadrature are presented in the tables as Π, to represent the "population" value. The average squared deviation from this population value ($s^2|\Pi$) over the 10 estimates per problem was used as a measure of the accuracy of a given method. The average squared deviation from the observed mean ($s^2|\bar{p}$) based on each set of 10 samples was also computed. It is the square roots of these measures ($s|\Pi$ and $s|p$, "standard deviations") which are presented in Table 1. The standard deviations obtained for the simple Monte-Carlo method were used as the baselines by which relative amount of variation for different problems could be evaluated. These ratios of standard deviations are also presented in Table 1 for each set of problems.

The first observation which should be made about the results is an apparent equivalence of the two measures of variability, $s|\Pi$ and $s|\bar{p}$. That is, the degree to which one Monte-Carlo method is more precise than another for a given problem appears to be independent of whether the deviations of the estimates are taken about the observed mean or about the population value. Of course, such a generalization can be made only with respect to unknown integrals based on single common factor distributions. Equivalence of the measures, if equivalent over all types of problems, could be taken as an indication that the Monte-Carlo estimates, even though highly variable, are unbiased estimates and can be expected under increased sampling to converge to the true population value.

To further clarify the form of the results, the ratios of standard deviations were extracted from Table 1 and regrouped to form Table 2. Noting that a ratio of standard deviations above 1.0 indicates superiority of the importance sampling method, whereas a ratio below 1.0 favors the simpler sampling procedure, a striking characteristic of Table 2 is that neither method is consistently superior over the different types of integrals being evaluated. The ideal result, of course, is to find some method which yields estimates with a marked reduction of variance on all problems. With the results shown here, the types of problems for which one method might be superior to another is a matter only for hypothesizing. Perhaps ultimately, the most economical procedure with respect to computer time will be the design of some test in which the type of probability integral to be evaluated is examined by the computer before it proceeds to analysis by one of several alternate methods. Or perhaps at most, these comparisons of results may have bearing on some entirely new approach to the problem of evaluating multivariate normal integrals.

An independent research project is being conducted by Mr. Cecil Johnson at BESRL on increasing the goodness of fit of the single common factor sampling distribution to the multivariate normal distribution of interest to increase the precision of importance sampling. Some preliminary results by Mr. Johnson indicate that using improved methods to determine the parameters from which the common factor random entities are generated can result in an appreciable reduction in variance. That such an approach is a fruitful one is supported by the data presented in this paper. In fact, the one striking observation which comes from Tables 1 and 2 is the superiority of the "good" approximation sampling distributions to the "poor" approximations in yielding minimum variance estimates. This advantage shows up in all 24 of the problems where goodness of fit is compared and goes as high as 42 to 1 in problem 4 with 8 variates. One should be wary, of course, of the fact that, when the sampling approximation is very good (i.e., when the sampling distribution is nearly identical to the distribution associated with the unknown integral), the variable components on which an importance sampling estimate is based are very small relative to the scaling constant computed by quadrature. Consequently, the variance of the estimate will be very small. Therefore the superiority shown in problems 1, 4, 7, 10, 13, and 16 is partly a consequence of the fact that the unknown distribution is one of the rare distributions whose integral value is near to the value computed by the given quadrature formula, a situation not to be encountered often. The real test of an importance sampling approach is whether an advantage can be observed when the sampling approximation is only moderately good or poor. Such an advantage does show up in problems 3 (for 4 and 8 variates) and 9 (for 4 variates), poor approximation problems, but not in other poor approximation problems, 2, 8, 15 (for 4 and 8 variates) and 9 and 14 (for 8 variates).

It should be pointed out that the determination of a suitable single common factor distribution and the manner in which random entities are generated from this distribution is not a straightforward procedure. By varying such a procedure, precision of the estimates based on even a poor sampling distribution can be improved. The results presented here may be considered relatively crude with respect to this aspect of the problem; improvement is expected when the procedures under investigation by Mr. Johnson are incorporated into the techniques described here.

Looking again at Table 2, estimates do appear to favor slightly the importance sampling approach when the region of integration is over the center of the distribution. The best results, problem 4 for 4 and 8 variates, occur when the range of integration is from -1. to +1., the center, even though the associated multivariate normal distribution is the least concentrated about the center (i.e., all r's = .10). Furthermore, the ratios of standard deviations are greater than one in all but

one of the problems designed for the central region, regardless of the type of distribution being integrated. The importance sampling method tends to be relatively less efficient when tails are included in the integration limits. For example, problems 5 and 6 for 8 variates indicate a gross failure of the importance sampling method, although these problems are also based on poor one common factor approximations to 8 variate distributions. Furthermore, any observation on tail results cannot be stated too conclusively, since no data is yet available in which only the tail regions are examined to the exclusion of any of the more central regions.

Clearly, the relative advantage of one sampling method to another is highly sensitive to variations in the region of integration relative to the structure of the correlation matrix. For instance, the ratios for the four variate distribution characterized by a single common factor correlation matrix with large positive elements (problems 1, 7, and 13) increases by a multiple of about two when the integration limits include a variety of ranges, even though the probability area is small. By contrast, when the correlation matrix has very small positive elements, the advantage of the importance sampling method decreases to about one-half when the tails are included (problems 4, 10, and 16).

An attempt was made to relate advantage of the importance sampling approach to size of the probability region, but no consistent trend could be observed. It would be of interest to do additional experiments to evaluate the efficiency of comparable regions of integration when the only independent variable is magnitude of the probability region.

Summary

Experimental results have been presented to evaluate two different methods of Monte-Carlo sampling to integrate the multivariate normal distribution. The precision of the estimates for the two methods is compared from the magnitude of the variances of the estimates over independent samples. The only general observation which could be based on the results was related to the goodness of fit of the sampling distribution used in the importance sampling approach to the unknown distribution. When the sampling approximation was a good one, the importance sampling method was superior to the brute-force method. When the approximation was poor, the more complex method was inferior. Of course, other distributions might replace the distribution used here for importance sampling with a substantial improvement in the precision of the probability estimates. Alternatively, the probability region might be divided into strata and some other type of sampling distributuion be used only for estimating probability regions under the tails. Finally, more work is being done at BESRL to improve the adequacy of the approximation of the one common factor distribution to a multivariate normal distribution of interest, and information from this new research will be incorporated into the techniques described here.

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"Management and the Systems Analysis Mystique"

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Introduction

To be successful, the modern manager must be able to assimilate large quantities of data. It has been said that our knowledge has doubled in the past twenty years and it is estimated that it will double again in the next ten years. Not only does this affect the scientific community but it affects all of us. Every day new developments occur which generate reams of data which are later grouped, analyzed, and published. As a result, the modern manager finds himself confronted with an ever increasing amount of useless data. Surrounded by data on every conceivable facet of his operation, the manager diligently searches for a method of separating information from chaff. During this search, the concept of systems analysis is first discovered. An aura of contentment now settles about our executive as the mystique of systems analysis exerts its influence. Unfortunately, the decision maker often finds that systems analysis has provided additional data, but no additional information. Since so much controversy surrounds this subject, an intensive examination of the nature, value, and limitations of systems analysis is needed.

Definition

Systems Analysis is defined as a systematic approach to problem solving which utilizes quantitative management science techniques to develop and evaluate a spectrum of solutions to long range problems. The length of the effort does not determine if something is to be classified as a "systems analysis study." If all steps in the enclosed methodology have not been properly considered, this effort is merely an evaluation based on expertise. Unfortunately, too many incomplete efforts, which can lead to poor decisions, have been termed "systems analysis studies." To arrive at an optimum solution, either the effectiveness of the system should be maximized or the costs minimized. Systems analysis can be applied to materiel effectiveness, organizational structure, and product mix problems. During the conduct of a systems analysis study, alternatives are developed to meet specific requirements for a variety of environments; then the alternative is selected which best satisfies these requirements.

System & Subsystem Relationship

Systems analysis is applicable to any type of problem if the technique

is adapted to take into account the individual aspects of each problem. If the systems analysis effort is to be productive, it is vital that the system under consideration be carefully defined. A system is composed of men, material, and machines; and the limits, relationships, and effects of each part of the system must be explicitly separated from the environment, which is defined as everything outside the system. Furthermore, each subsystem must be clearly defined and its relation to other subsystems and the system established. In practice, defining the subsystem boundaries and determining the interface coefficients is extremely difficult. After developing the subsystem relationships, the value of each parameter must be related to overall effectiveness. If a systems analysis effort is to be successful, a clear distinction must be made between each subsystem, the system and the environment.

A final source of difficulty arises if past studies have been conducted to optimize certain technical characteristics of the system and an attempt is made to sum the results of these technical subsystem studies into a system study. The results of these subsystem effectiveness studies cannot simply be summed to give total effectiveness because the objectives of the system study are not necessarily the same as the objectives of the past subsystem studies. Furthermore, the system operates under different constraints than the subsystems. Realizing that a systems analysis study is composed of a number of subsystem studies, both common constraints and a method of assigning relative weights to the results of each subsystem study must be developed. If the above factors are not considered, a less-than-optimal solution will be obtained.

Time Frame

One of the more important points illustrated by the definition of systems analysis is that long range problems are specified. Does this mean that short range problems must be solved using other techniques? A review of current operations research publications indicates that short range problems are handled by resource analysis techniques, however, resource analysis is essentially the same as systems analysis. The only difference between these analytical approaches is that cost is usually not the most important factor in the short run. For example, it might be demonstrated that a particular alternative is much cheaper than other alternatives, but personnel or special material requirements of this alternative might negate its use in the short run.

Continuing Process

It has been asserted that systems analysis is used for both long and

short range problems. Systems analysis is a continuing effort from the concept formulation stage, through feasibility testing, through all development stages, into production and throughout the life of the product or the idea. At each stage, information which is both more pertinent and more reliable becomes available to the analyst. Since the analyst is continually acquiring information, the decision maker or a member of his staff must maintain close contact with the study to verify that the current facts and assumptions are valid. By monitoring each phase of the study, time and money can be saved because the manager will be able to make good timely decisions and eliminate alternatives which could never be implemented.

Since systems analysis is a continuing process and since the manager is continuously involved, it becomes evident that present decisions may be exactly opposite to decisions made in the past. This is natural because as time passes the goals, alternatives, criteria, and environment change; necessitating a complete re-evaluation of the entire project.

The Computer

Much has been written about Robert McNamara, systems analysis, and computers. Since these subjects are often discussed in the same article, the reader often associates systems analysis with computers. This association is not justified. Systems analysis is a technique while the computer is a tool utilized by systems analysts. In fact, a computer is not necessary for systems analysis; it merely speeds calculations which the systems analyst has determined are necessary to solve the problem. Once the analyst has determined what must be calculated it is relatively easy to program this so it can be run on a computer.

Value and Use of Systems Analysis

Systems analysis is a tool of the manager which enables him to avoid broad generalizations. This tool is used by the manager to allocate resources, to optimize under a particular set of circumstances, to compare alternatives and to establish requirements. In comparing alternatives, in order to make a decision, the manager is interested in differences, not similarities, among alternatives. The real value of systems analysis lies in the fact that it is a systematic approach which forces a manager to structure his thinking to the problem at hand. By forcing differentiation of qualitative and quantitative variables and by listing the assumptions, techniques, and limitations of the study; the problem areas are highlighted. In other words, at this point the manager finally knows what must be decided.

This author believes that the present day manager, who most theorists assume is interested in making an optimum decision, is actually interested in eliminating the alternatives which could prove disastrous. Since only the results of the one alternative selected by the decision maker can be observed, the decision maker is sitting pretty if he can avoid obviously poor decisions. The reason for this is that once a decision has been made, even if the best alternative has not been selected, the manager can make this solution work.

Another advantage of systems analysis is that it may demonstrate to the manager that a decision may be postponed. The point will not be belabored that choosing to do nothing is a decision. If a decision can be postponed, the study can be revised to take advantage of more accurate and timely information, which increases the usefulness of the study. In addition, since every manager operates in a dynamic environment, this means that the competition has less time to react to the decision. This holds true when possible strategies of the United States are being considered, when a manufacturer is engaged in negotiating a union contract or when developing optimum organization techniques. The importance of delaying a decision until it is needed is evident when past prognostications of the future are evaluated against reality.

Cost-effectiveness studies are also a good source of documentation. The subjects which should be discussed in the summary of the cost-effectiveness study (FIGURE 1) enable the manager and future users to analyze the value of the effort. In addition, the progress of a study can be ascertained by determining whether or not the steps in the general methodology (FIGURE 2) are being followed.

<u>Limitations of Systems Analysis</u>

Like everything else, systems analysis has its limitations. In systems analysis, the real world is represented by a model. Since a model is one level removed from reality, an optimum solution to the problem, as defined in the model, may not work in the real world. Furthermore, a good systems analysis study requires a great deal of effort which means that both competent people and the necessary time must be available. If either of these factors is missing, the resultant effort will be either poor or incomplete. If an incomplete effort is submitted as a "systems analysis study", an unearned air of respectability accompanies the submission. The false confidence inspired by this incomplete effort may lead to poor decisions in the future.

A second problem arises when data is not available or only low confidence values can be placed on this data. The value of good relevant data cannot be overstated. The last factor to be considered is the effect of a good decision based on a successful study. As was discussed, a decision is valuable for a certain time frame. After this time period, the environment changes of its own accord or the competition moves to change the environment so that another systems analysis effort must be prepared for the new problem.

General Methodology

Fortunately for systems analysts, no cut and dried method of performing these studies exists. Each problem is different, each environment is different and the techniques of systems analysis are constantly changing. The problem tells the system analyst the direction to follow. For these reasons it is easy to see that the systems analyst must be both ingenious and flexible, but it also seems reasonable that some way should be developed to take advantage of any similarities. For this reason, a general methodology (FIGURE 2) has been developed. Each of the steps in the methodology will now be discussed.

Defining the Problem

As has often been said, defining the problem is the most important part of any study effort. If the problem is not clearly defined and the scope of the effort spelled out, interface problems and suboptimization may result.

Problem definition, which should therefore be the first part of any study, begins with some statement of general objectives, such as, "this Army will have the best possible communications" or "this company will operate so that each person receives quality merchandise and good service for a reasonable amount of money". These abstract goals must now be turned into specific realistic requirements which is extremely difficult in practice. The first question encountered deals with the scope of the problem. Do we mean that we will provide communications under all possible conditions? How is communications defined? What do we mean by the "best possible" communications? In considering the business concern, how do we define quality and good service, what is a reasonable amount of money, and are we talking about all products we sell or only those which we produce and sell?

During this translation of the abstract to the realizable goal, the

decision maker must participate because all alternatives will be evaluated against this requirement. This aspect of the methodology assumes greater importance when it is remembered that certain aspects of systems operation can be improved without improving the overall efficiency of the system. Furthermore, if the requirements are set too high, the system may be overdesigned. Even though overdesign increases the cost and effort involved in product development, the initial phase of problem definition is often summarily concluded. To avoid this problem, both minimum and maximum requirements should be set. Specific requirements are often expressed in terms of quantitative standards, but qualitative requirements are often forgotten. Representative qualitative requirements must be developed and should be listed separately from the quantitative requirements. For example, requirements for personnel with certain skills and special time constraints must be spelled out.

Since these requirements are to be used for evaluation, it is important that no alternatives are precluded by the definition of the problem. The different levels of problem definition must be considered. For example, if one radio is simply to be compared against another radio for communication over a certain distance, it is relatively easy to develop a requirement for this. Note how problem definition becomes more difficult as the radio is compared with another means of communication such as cable to determine which provides the best communication. Now expand the problem so that you compare this radio versus an improved weapon to determine when overall combat effectiveness has improved. In order to take into account all state-of-the-art advances, and to guard against overdesign, a significant amount of time should be spent defining the problem.

Defining the Environment and the Mission Mix

For a product to be profitable, the proper market for this product must be determined. Similarly if a weapon system is to be effective, it must be able to meet a certain threat. However, the extent of the value of this weapon system also depends on how often the threat materializes. For these reasons, it is evident that systems analysis cannot be performed in a vacuum. The conditions under which the system will operate and the number of times this system is needed must be defined.

If the objectives are to be realized, a clearly defined mission mix must be provided. The type of mission and the frequency of occurrence of each

mission must be determined. Although this appears obvious, a review of many systems analysis studies shows that it may not be so obvious. For example, real time computer capability is extremely advantageous to a manager. With such a system, a manager could develop a program so that he could receive an immediate printout on the background of each employee. However, how often does the manager need this information immediately? What percentage of the personnel decisions which a manager makes require immediate information? Granted the manager has received information faster, but has he increased the effectiveness of the personnel system? Another example of this concept is the development of a system which is to perform two or more functions. To develop the best system the relative need for each function must be known.

If the environment is to be realistic, close attention must be given to the time factor. If a product is needed in four years but development of the item requires eight years, it would be a waste of time to develop the original item. The operational situation must be timely. It must reflect the conditions under which the product will be utilized. Furthermore, if the product is to operate over a certain period of time, provision for change must be built into the environmental section of the study. If a product has a life cycle of ten years and requires eight years to develop, the scenario, which provides background information, should reflect the conditions eight years from now to eighteen years in the future. State-of-the-art advances must be considered.

Suppose all the above factors have been considered, one factor still remains. How are these missions to be weighted relative to one another? One thing is certain, all missions will not have the same amount of importance; therefore, if an optimum product is to be developed, weights must be assigned to each mission. Who assigns these weights? One of the better methods of assigning relative values is to bring together a number of experts with different backgrounds. These experts, without benefit of discussion, are then asked to rank the missions in order of importance. After listing these missions in order of importance, the five or six most important missions are considered by the group. Since these five or six missions will probably cover 90% of all missions, the experts then assign percentage values to each of these missions. After normalizing these figures, a relative mission mix will have been developed. This mix provides a beginning. In the analytical section of the methodology, it will be demonstrated how this relative mission mix can be easily modified or other missions added to determine the effect on the outcome of the study.

Developing the Criteria

The criteria is an approximation of the objective. It serves as the standard against which the alternatives are compared. Since there are many types of objectives, there will be many types of criteria. For example, a go/no go criterion is valid for some types of studies while degrees of success must be considered in other studies. The problem indicates to the study group what type of criteria to develop.

In many cases, subjective considerations become the critical factors in the selection process. For example, how will morale or coordination be affected by each alternative? Since it is obvious that each person will weight these factors differently, they should be listed as factors affecting the decision. (Note how these factors differ from the qualitative requirements discussed previously.) One other way of handling these qualitative factors might be considered. A group could be set up to apply quantitative values to each qualitative factor. The major shortcoming of this approach is that these quantitative estimates of qualitative factors must now be combined with pure quantitative factors.

The criterion is usually expressed in the following manner: provide the same level of effectiveness for all alternatives; then select the one with the least cost or vice versa. As can be imagined, this comparison can be performed for many different cost or effectiveness levels and different results will probably be obtained at each level. Since this doesn't help the decision maker, maximum and minimum standards for cost and effectiveness should be developed to reduce the scope of the problem and incremental analysis techniques should be used to show when the cost of additional effectiveness becomes prohibitive. After utilizing these aids in developing quantitative measures of effectiveness, the qualitative factors or subjective considerations often become the deciding factor.

Having considered both cost and effectiveness (the derivation of the name cost-effectiveness study), it would appear logical to develop a cost-effectiveness ratio. However, such a ratio is misleading for the following reasons: (1) the cost of an item depends on the quantity produced; therefore, the C/E ratio will vary depending on the amount, (2) the ratio is affected by changes in either the numerator or the denominator, (3) the level of effectiveness may not reach the minimum level, yet a good ratio could exist. The first two problems can be eliminated if either cost or effectiveness is held constant and the development of a minimum standard will eliminate the third problem. Therefore, a C/E ratio can be useful if the [illegible] standards discussed above are implemented.

To conclude this section, importance factors will be discussed. The importance factor is the value of one system parameter relative to other parameters. This concept is easily understood if it is recalled that effectiveness depends on a number of things. For example, the effectiveness of a plane is dependent upon speed, range, maneuverability, availability and many other factors. But how are these factors related to overall effectiveness? Does speed contribute 30% to total effectiveness? Is speed twice as important as range? This weighting problem was discussed earlier in the paper and the use of a group of experts to develop these importance factors still appears to be the most promising solution. After the study has been completed, a sensitivity analysis can be run on each factor to determine how it affects the results of the study.

Determining the Alternatives

Having defined the problem and developed the selection criteria, all alternatives which may satisfy the requirements should be listed. The problem must be stated in general terms so that no alternatives are precluded. Ingenious people with broad backgrounds must determine these alternatives, for only then can the decision maker be certain that all alternatives have been considered.

In addition, the internal and external tradeoffs for each alternative must be considered. For example, if the objective is to destroy an enemy position, combat troops may be aided by either tactical air support, ground fire support, or a combination of the two. But many types of air and ground fire support exist. For instance, tanks, artillery, mortars and vehicular mounted weapons provide ground fire support and each of these categories can be further divided. Artillery could be divided into 105mm guns, 155mm guns, and 175mm guns. Once a weapons system has been selected, its effectiveness can be changed by varying its performance or its availability characteristics. Availability is determined by intrinsic availability and operational availability, and intrinsic availability is dependent upon reliability and maintainability.

As illustrated above, differences in degree and in kind exist at each level of the system.

Determining the Relevant Variables, Assumptions and Facts

Due to cultural and educational differences, the same word can have

many different meanings. Not only will people disagree on the definition of a word but they will disagree on the importance of the concept which the word represents. Since these concepts have not been universally defined, it becomes even more difficult to measure them. Therefore, each concept and characteristic must be explicitly defined if a cost-effectiveness study is to be meaningful.

Since a study is conducted to determine solutions to an existing problem, a clear differentiation must be made between assumptions and facts and each assumption and fact must be listed for the decision maker. In addition, the source of each fact and the reason for each assumption should be noted. Only in this way can the decision maker check the reasonableness of the study and ascertain if the real problem is being attacked.

The factors which will make up the effectiveness value are then selected by a group of experts. To do this all factors which are thought to affect the effectiveness value are determined. After structuring these variables according to importance, the six most pertinent are selected. The reason for selecting six variables is that the author believes that 90% of total effectiveness is determined by these variables. If this surmise is wrong, no damage has been done because the effect of other variables may be tested by sensitivity analysis. After selecting these variables, the group of experts assigns weights to these factors. These variables must be chosen so that any significant change to the system will be immediately evident in the model results.

Generating the Data

At this stage of the study plan, the problem, criteria, and alternatives will have been defined and the problem will indicate to the study group what data is needed. Data is needed on both the cost and effectiveness aspects of the study, but the necessary data in the proper form is difficult to obtain. Even though the time, effort and cost involved in gathering data is high, confidence in the validity of the data is often low. There is no simple solution to this problem, and a number of articles have been written on data collection, but it should again be stressed that a study will not be successful unless a sufficient amount of money and talent are committed to this step.

Developing the Model

It becomes obvious in this section that model development and data

generation should take place concurrently because a continuous feedback loop exists between these 2 phases. Gene A. Markel defines a model as follows, "A model is a representation of a thing; the more important parts of the real thing are incorporated into the model, and appropriate analogs are used to replicate essential structural and functional characteristics." The model abstracts only those parts which are important to the problem. This means that no model is completely realistic, because many intangibles and concepts which are difficult to define are neglected. However, the value of a model depends on its ability to indicate the merit of various alternatives, not on how accurately the model is a reproduction of the real world.[1]

Any model chosen must illustrate the tradeoffs between effectiveness gained and resources utilized. For this reason, effectiveness and cost submodels are developed. The effectiveness submodel is divided into performance and availability submodels, and the cost model is broken into research and development, initial investment, and operating and maintenance submodels (FIGURES 3, 4 & 5). Each of these submodels is further divided into its elements as illustrated in the area communications example. What this means is that just as a system is a hierarchy of subsystems, so a model is a hierarchy of submodels where each submodel is composed of a number of algorithms. Furthermore, just as subsystems must be integrated into the system so must submodels be integrated into the model. This is a difficult task for the model builder who must develop and interface each level of the model.

Modular design is the tool which enables the designer to build a multi-level model. In a modular model, the failure of an element on a certain level does not affect other elements on the same level. This concept enables the system designer to localize cause and effect relationships. As utopian as this idea sounds, it does not hold completely true in the design of a model because submodels are not independent of each other. Therefore, the relationship of each element to other elements and to the next higher level must be clearly defined. This is extremely difficult. The amount of detail in each submodel and the degree of detail to which the interfaces are stated is dependent upon the time, money and expertise available. Expertise is the greatest limiting factor.

It is easy to see that continual feedback is necessary in model

[1]G. A. Markel, "A Concept for Modeling and Evaluating [illegible] Producing [illegible] publication [illegible] (January [illegible]), p. 6.

development. Each submodel is related to the model and other submodels and a continuous exchange of ideas is necessary so that a complete description of all interface algorithms is developed. In addition, the decision maker must be continually briefed because he will be called upon to provide further guidance for submodel developers and to insure that the correct problem is still being attacked by the model builder.

Effectiveness Model

Having introduced the concept of modular design of submodels, the effectiveness and cost models will now be discussed. An overview of these models is shown in figure 3. Many different groups have developed methods of estimating effectiveness. The Weapons System Industry Advisory Committee (WSIAC) appears to have been the first group to establish a method of establishing effectiveness. To determine system effectiveness, this group used a matrix concept which represents effectiveness in terms of capability, availability, and dependability of the equipment. It appears that a simpler method of determining effectiveness exists. Total effectiveness is determined by manipulation of the performance and availability submodels.

Performance Model

There are no general elements which I can group under this heading because each problem has different measures of performance. For example, speed and maneuverability are extremely important when considering the measure of performance of an interceptor airplane, however, they are of no concern when considering the measures of performance of a manpack radio. The problem indicates the important parameters and an example of this is provided in the area communications example. (Appendix 1)

Availability Model

It is much easier to develop a general model of availability. As can be seen from figure 4, availability is dependent upon two primary factors, intrinsic availability and operational availability. Availability is the probability that the system is able to function satisfactorily at any point in time when used under stated conditions, where the total time considered includes operating time and repair time. (Repair time is further divided into active repair time, administrative time and logistics time.) Intrinsic availability is a function of reliability and maintainability only. As can be imagined, the best way to improve the availability of equipment is to increase intrinsic availability. This can be achieved only if a major reliability and maintainability effort is begun early in the design stage.

The other major factor influencing availability is operational availability. From figure 4, it can be seen that two primary factors determine operational availability. These two factors are attrition rate and repair time. Repair time is determined by serviceability, logistic time, administrative time, and failure rate.

Undoubtedly, the reader is happy to know the factors which determine availability, but he would probably be happier if the interrelationships were shown. Three levels of detail are shown in the availability model. Algorithms must be developed which show how elements are combined to form submodels and how submodels are combined in the model. For example, design reliability and design maintainability are combined to give the value of intrinsic availability. Intrinsic availability and operational availability are now combined to give a measure of availability.

Since submodels are not independent of other submodels, additional algorithms must be generated which show these relationships. For example, design maintainability is a determining factor of availability, but it also affects repair time.

Cost Model

The life cycle costing concept considers R&D, initial investment, and operating and maintenance costs over the total useful life of the system. In the R&D category, all stages of development should be considered. Figure 5 illustrates the basic phases of development in the R&D cycle. The R&D cycle begins with the exploration development stage in which the feasibility of a product is tested, and ends with operational systems development. During the development phases, various systems development approaches are evaluated and the best approach selected and implemented. The costs which are found in each of these stages have been examined in detail and many check lists have been developed.

The investment costs involve all costs expended to manufacture a product. A summary of the major elements is given in Figure 5. In this phase, the costs of production facilities, labor, and materiel are considered. Production testing and quality assurance costs are also considered here. Two other high cost factors are the cost of the initial supply of repair parts and the cost of government furnished equipment.

The last cost category is operating and maintenance costs. Operating

costs and maintenance costs provide the bulk of these costs. The other major factors are personnel and training costs, and supply operations costs. An example of the cost of supply operations is the cost associated with running a depot or maintaining a headquarters.

Each of these submodels has been extensively described. Military Standard 881, which has not been approved, provides the standard DOD work breakdown structures for eight types of hardware systems and defines which costs fit into each category. In addition, completed cost-effectiveness studies provide further documentation.

Having determined the cost categories to be used, the remaining problem is to gather the costs. Since most studies are performed on systems in the experimental stage, it is soon discovered that no cost information is available. This means that a relationship between the desired cost and some known physical or performance characteristic of the system must be found. Then an algorithm is developed which relates cost to the value of this characteristic. For example, the Air Force has effectively used aircraft weight to predict airframe cost and recently a relationship has been found between truck weight and fuel consumption. In these cases, regression analyses were performed on historical data from existing similar systems. Regression analysis is a statistical technique which illustrates mathematically the relationship between two or more variables and assigns confidence levels to those relationships. After production costs are estimated, learning curve theory shows how these production costs decrease as experience is gained.

There are other factors to be considered while gathering costs. Basically, the costs which are the same for all alternatives (fixed costs) are only valuable for determining whether the cost ceilings have been pierced. In addition, all money that has been obligated or spent is a sunk cost and should not be considered because systems analysis can demonstrate when past decisions should be changed, but it cannot bring this money back. Since the objective of the study is to select the best alternative, only costs which are different for each alternative should be considered. This is differential cost theory.

There are certain military policies such as procurement and overhaul policies which must be considered when designing the overall

cost equation. The problem tells the analyst how to combine all relevant costs. For example, a general unit life cycle cost for a system would follow this form:

$$\text{UNIT COST} = \frac{\text{R\&D costs + initial investment + life cycle operating and maintenance costs}}{N} \quad \begin{matrix}\text{(where N is the)}\\ \text{(number of units)}\end{matrix}$$

Algorithms must be developed to relate all elements in each category. As seen in Figure 5, the total R&D cost is found by adding exploratory development, advanced development, engineering development and operational systems development costs.

Another element to be considered is that the value of money changes with time. This can be seen by checking the interest you have received in the past year. Since the normal life cycle of a system is approximately ten years, different amounts of money will be spent during each year of the life cycle. If two alternatives have the same effectiveness, but one requires a large initial investment while the cost of the other is spread equally over a number of years, the second alternative is cheaper. How much cheaper depends on the discount rate assigned for the study. This issue has generated a lot of controversy because no two people agree on the discount rate to be utilized or on the estimated useful life of the product. To solve this problem a number of discount rates should be used and the effect on total cost evaluated.

Exercising the Model

After the model has been developed, it must be manipulated to provide information on each alternative. If the problem is simple the manipulation can be done by hand, otherwise a computer is utilized. Simulation is often utilized in systems analysis because it provides quantitative answers to specific questions which do not require the participation of a decision maker. The great time compressions and control conditions obtainable with computer simulation provide data which is useful for more quantitative and rigorous analysis. This time compression is due to the fact that either probabilistic or deterministic decision rules are written into the simulation. The problems that are best studied by computer simulation are those which require large sample sizes in order to perform adequate statistical tests.

To gain the most from the use of simulation, the program must be

written so that the variation of the critical parameters can be easily detected. If parameters become less important, they are modelled as environmental conditions. However, as a variable becomes a limiting factor in the results, it is modelled in more detail.[2] The model is continually being modified because data may not be available, because additional knowledge indicates that some data may not be relevant, or because some parameters become less critical to the analysis.

As with other computer programs, the cost of designing and running the simulation is proportional to the length of the program and the complexity involved.

Analytical Effort

In this stage, all alternatives are compared against the standard and against each other. Three levels of analysis should be performed in any cost-effectiveness study. The initial analysis should be general in nature and is designed to eliminate all alternatives which cannot meet the minimum requirements or the cost ceilings. Next, an intensive analysis is performed in which detailed cost and effectiveness estimates for each remaining alternative are developed. At this point, some additional alternatives will probably be eliminated. An incremental analysis (marginal analysis) is then performed on the remaining alternatives. This analysis will show any break-points which may exist. Since the additional effectiveness for a fixed amount of investment will markedly decrease beyond this point, this test provides another indication as to which alternative should be selected. The results and confidence coefficients for the detailed analysis and the incremental analysis, along with subjective considerations should now be presented to the decision maker.

Sensitivity Analysis

Even though he has continually participated in the conduct of the study, the decision maker may be plagued by a series of "what if" questions. Since data is generated with different levels of confidence and since the use of expert judgment was utilized extensively in this methodology the manager must be provided with some type of validity check. A sensitivity analysis provides this check and helps to eliminate some uncertainty. In sensitivity analysis, certain variables or environmental factors are changed so that the effect on the results may be determined. Using this type of analysis, the contribution of each variable to total effectiveness can be determined. The importance of a sensitivity analysis in the systems analysis effort cannot be overstressed. This technique provides the

[2] M. A. Geisler, "Man-Machine Simulation Experience," Rand publication P3214 (August 1965), p. 5.

means of changing assumptions, varying decision rules, modifying environmental conditions and considering the reaction of the competition. If the study were not structured so that sensitivity analyses could be performed, the study would be useful for only one set of assumptions and environmental conditions. Since the world is changing rapidly, the results of the analysis would be outdated by the time the study was completed.

Each submodel should be developed so that mathematical programming techniques can be utilized. To use mathematical programming an objective function, mathematical function, and the constraints and restrictions on variables must be defined. Mathematical programming techniques enable the analyst to optimize under certain restrictions which is exactly what we are trying to accomplish with a systems analysis study. Mathematical programming techniques make it easier to perform sensitivity analyses.

The concept of sensitivity analysis becomes even more valuable when it is recalled that the specific requirements which we have satisfied are only an approximation of the objective. Thus, sensitivity analysis enables us to determine if the proper problem was solved. Sensitivity analysis also enables us to determine maximum capabilities under fixed conditions. This is simply a modification of the basic technique in which time, materiel or personnel requirements act as a limiting factor in the short run. In all cases, systems analysis should be conducted for both the most important and the most prevalent conditions. The question of what to vary and how much to vary must be considered because of the cost of the additional runs required for sensitivity analysis. Since the cost varies with the number of variations run, an experienced analyst must decide which parameters are to be varied and what degree of variation is needed.

Presenting the Results

The results of the study must be perfectly clear and understandable, because only this finished product is transmitted through the different levels of management. The elements which should be contained in the final report are shown in figure 1. In order to make certain that these factors are clearly discussed, the final report should contain a short summary which considers each of these elements. Since the report contains two levels of detail, the reader can first read the summary; then turn to the detailed discussion of the parts that interest him.

Two points should now be made. In the section in which the results

of the study effort are presented, the benefits of the selected alternative should be discussed and possible problem areas highlighted. Since some controversy exists about whether or not recommendations should be included in the final report, it is shown in the figure as an optional section.

Conclusions

In this paper, the nature, value, and limitations of systems analysis were discussed, a general purpose methodology developed, and this methodology applied to an area communications problem. In addition, the continuing nature of systems analysis and the requirement for the close participation of the decision maker has been stressed. Systems analysis provides answers to two types of questions. In the first type, a certain level of effectiveness is required and the alternative selected is the one which costs least. Systems analysis is also used to determine the worth of additional capability.

Systems analysis was defined as a systematic approach to problem solving which utilizes quantitative management science techniques to develop and evaluate a spectrum of solutions to long range problems. However, this concept can be applied to short run problems if it is recalled that time or personnel considerations may be more important than money in the short run. Since a system is composed of men, machines, and materiel; a careful differentiation between the system and the environment is necessary.

Systems analysis is valuable, not because it places quantitative values on variables, but because it forces the designer to organize his thinking. If the procedures and the results of this systematic approach to problem solving are presented to the decision maker, the issues can be clarified; then, the manager will know what types of decisions must be made.

Appendix 1

AACOMS High Capacity Subsystem Example

General Objective

The proposed Army Area Communications High Capacity Subsystem is to be an integrated system composed of multi-channel field Army communications equipment which will provide secure high quality circuits capable of telephone, teletype, facsimile and data communication via radio and cable. This system is to provide line-of-sight communications to other Army area signal centers (30 mile radius), provide increased channel capacity and provide improved reliability and maintainability.

The technical control facility at the transmission center will have the capability of patching 600 channels, and the technical control facility of the operations center will have the capability of patching 300 channels. This system should be 100% mobile and shall be available to meet tactical field Army requirements in 1970.

To find additional general objectives, Army doctrine should be reviewed. The above was written to provide an example of what is meant by the term general objectives.

Specific Requirements

The charter authorizing the AACOMS system is very vague. In addition, even though qualitative materiel requirements (QMR's) exist for individual system components, no QMR has been developed for the system. Therefore, a QMR must be developed for the system; then specific requirements developed from the general objectives.

Representative requirements for the high capacity subsystem follow:

1. Capacity per Army Area Signal Center

   Transmission - 600 channels composed of combinations of 96 channel groups and 48 channel groups

   Operations - 300 channels composed of combinations of 96 channel groups and various smaller groups (presently under dispute)

2. Security. Different levels of security are possible. Either of the following could be designated as the requirement.

a. Secure from operational center to operational center.

b. Secure from transmission center to transmission center.

c. Secure from subscriber to subscriber.

Note that the first decision is whether or not there should be security. The second question is whether both tactical and administrative messages should be secure.

3. Range: 30 miles. (According to present Army doctrine, Army area communications centers will be located 30 miles apart.)

4. Availability. There shall be a 90% probability that the equipment will be operational 90% of the time.

5. Information rate: 19.2 or 38.4 KBS. (A multiple of 75×2^n so that this system will interface with other communications systems.)

6. Validity of Information. An acceptable error rate for digital communications or a postdetection signal/noise ratio for analog communications must be specified.

A representative group of experts who are cognizant of the objectives and familiar with the state-of-the-art of communications must be gathered together to develop the exact requirements for the system.

Environment and Mission Mix

Environment

1. Either a colocated operations and transmission center or separate operations and transmission centers must be specified.

2. Geographic and climatic conditions. In what areas of the world will this equipment be used? Various areas must be chosen and probabilities assigned to each area. Only in this way can equipment be developed to operate in a representative environment. For example: Southeast Asia is hot and humid while Europe is colder and not as humid. Even though the same circuitry would be used, the equipment package depends on the environment.

Mission Mix

It must be determined what specific requirements are required for what percentage of the total time. For example:

x range)
y security) needed for H% of the time
z availability)
.
.
.

A range)
B security) needed for J% of the time
C availability)
.
.
.
etc.

Both the representative environment and the mission mix must be determined by a group of experts.

Criterion

A minimum level of effectiveness must be determined and a cost ceiling must be set.

Basic Criteria

1. After setting the effectiveness of all alternatives to the same level, the alternative with the least cost is chosen or vice versa (as long as the minimum level of effectiveness and the cost ceiling are not exceeded.)

2. Qualitative requirements must be set. Any special requirements such as time and personnel should be set. For example:

a. No more than a signal company should be needed to man each Army Area Signal Center.

b. The cancellation clauses on some component contracts should be considered.

3. A list of qualitative factors which may influence the decision must be developed.

In this section, the method of evaluating the alternatives which exceed the minimum value should be determined, e.g. if the range requirement = 30 miles, how valuable is 40 miles of range or 50 miles of range?

Again, a group of experts should be utilized.

Alternatives

1. The existing system should be used as a benchmark alternative against which the other alternatives are compared. This comparison is made in addition to the comparison against the criteria.

2. Primary alternatives:

a. Method of patching — audio; audio/video

b. Channel groupings — 4, 6, 8, 12, 48 or combinations

c. Various levels of security

d. Cable or radio down the hill

e. Levels of system control

The alternatives are all combinations of A, B, C, D & E.

Note the internal tradeoffs of the above factors, e.g. intrinsic availability depends upon both reliability and maintainability. The external tradeoffs should first be considered. After determining the best solution, then the internal considerations should be optimized.

Assumptions and Reasons

1. For all alternatives which utilize audio-video patching, it is

assumed that the Department of the Army will authorize procurement of new security devices. This assumption is made because the needed security devices do not presently exist.

2. The year when the equipment will be fielded must be estimated.

3. Enemy capability and the state-of-the-art of communications in the pertinent time frame must be estimated.

4. The extent of interface required with other systems such as MALLARD and TACSATCOM and other subsystems such as the low, medium and troposcatter subsystems must be estimated.

5. The number of area signal centers must be estimated.

6. All other data and model assumptions must also be stated.

Facts and Documentation

1. The existing force structure as defined by CDC will be in effect in the proper time frame, e.g. signal centers will be located 30 miles apart and a signal company will man each signal center.

2. Pulse code modulation will be used.

3. Any other technical and administrative facts and the source of this information must be stated.

Relevant Variables

Performance:

a. Channel groupings

b. Security

c. Information rate

d. Validity of information (error rate (patching (multiplexers

e. System control (complexity (personnel requirements

Availability:

Intrinsic Availability (reliability
(maintainability

Operational Availability

1. Attrition rate

   a. Failure rate (all vulnerabilities

   b. Survivability (mobility
(silhouette

2. Repair time

   a. Failure rate

   b. Serviceability

   c. Logistic time

   d. Administrative time

The systematic use of expert judgment is necessary if variables which are representative of the requirements are to be chosen.

The last stages of the study process are covered in the methodology. I will conclude this example at this point by stressing that the validity and the source of the data must be stated and it must be recognized that model development and data generation affect each other. In the analytical effort, the importance of sensitivity analysis should again be stressed. The problem will indicate which variables should be changed and by how much.

In conclusion, figures 3, 4, 5 & 6 should again be reviewed.

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ELEMENTS OF THE FINAL REPORT & THE REPORT SUMMARY

1. General objectives
2. Specific requirements
3. Background information
4. The environment and mission mix
5. Facts
6. Assumptions
7. Reasons for assumptions
8. Decision criteria
9. Analytical techniques
10. Conditions under which these analytical techniques can be used
11. The alternatives
12. Results of the study effort
13. Recommendations (optional)
14. Documentation

FIGURE 1

STEPS IN GENERAL METHODOLOGY

1. Define the problem

    a. Define the objectives

    b. Turn general objectives into specific requirements

2. Define the environment and the mission mix

3. Develop the criteria to be used

4. Determine the alternatives

5. Determine the relevant variables, assumptions, and facts

6. Generate the data

7. Develop the model

8. Exercise the model

9. Analyze the results of the model

10. Present the results of the study effort

FIGURE 2

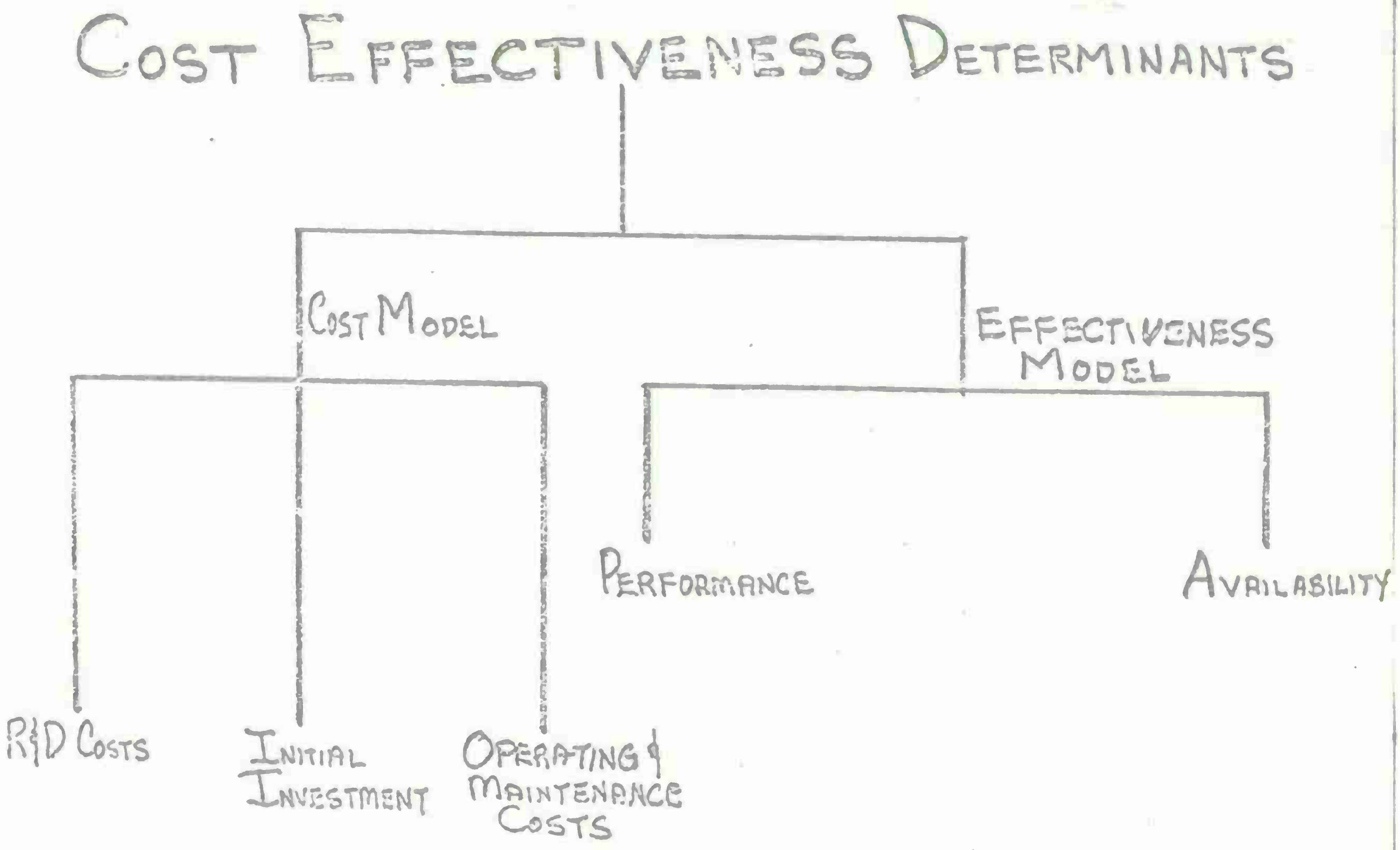

COST EFFECTIVENESS DETERMINANTS
COST MODEL
EFFECTIVENESS MODEL
R&D COSTS
INITIAL INVESTMENT
OPERATING & MAINTENANCE COSTS
PERFORMANCE
AVAILABILITY

FIGURE 3

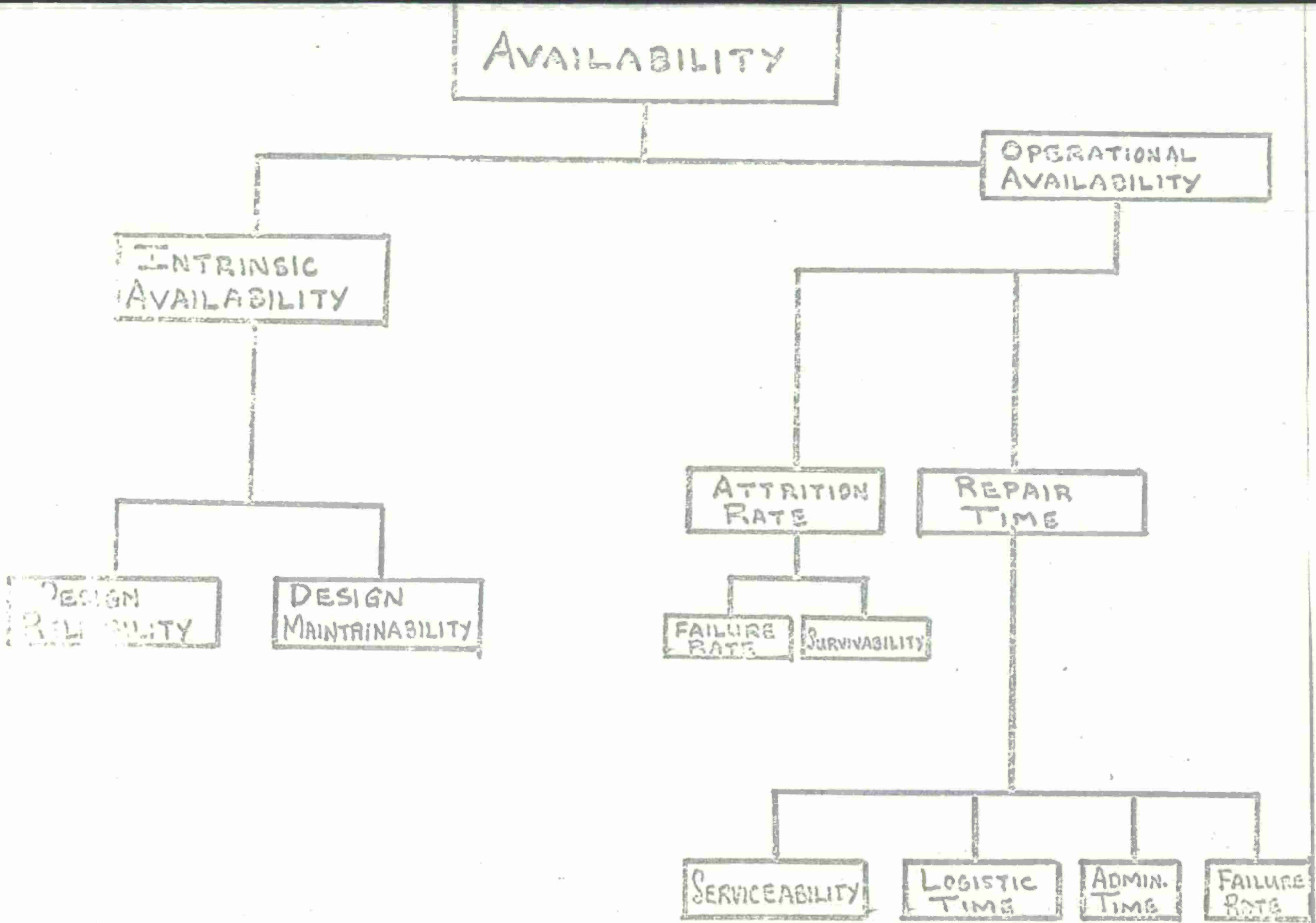

AVAILABILITY
OPERATIONAL AVAILABILITY
INTRINSIC AVAILABILITY
DESIGN MAINTAINABILITY
ATTRITION RATE
REPAIR TIME
FAILURE RATE
SURVIVABILITY
SERVICEABILITY
LOGISTIC TIME
ADMIN. TIME
FAILURE RATE

FIGURE 4

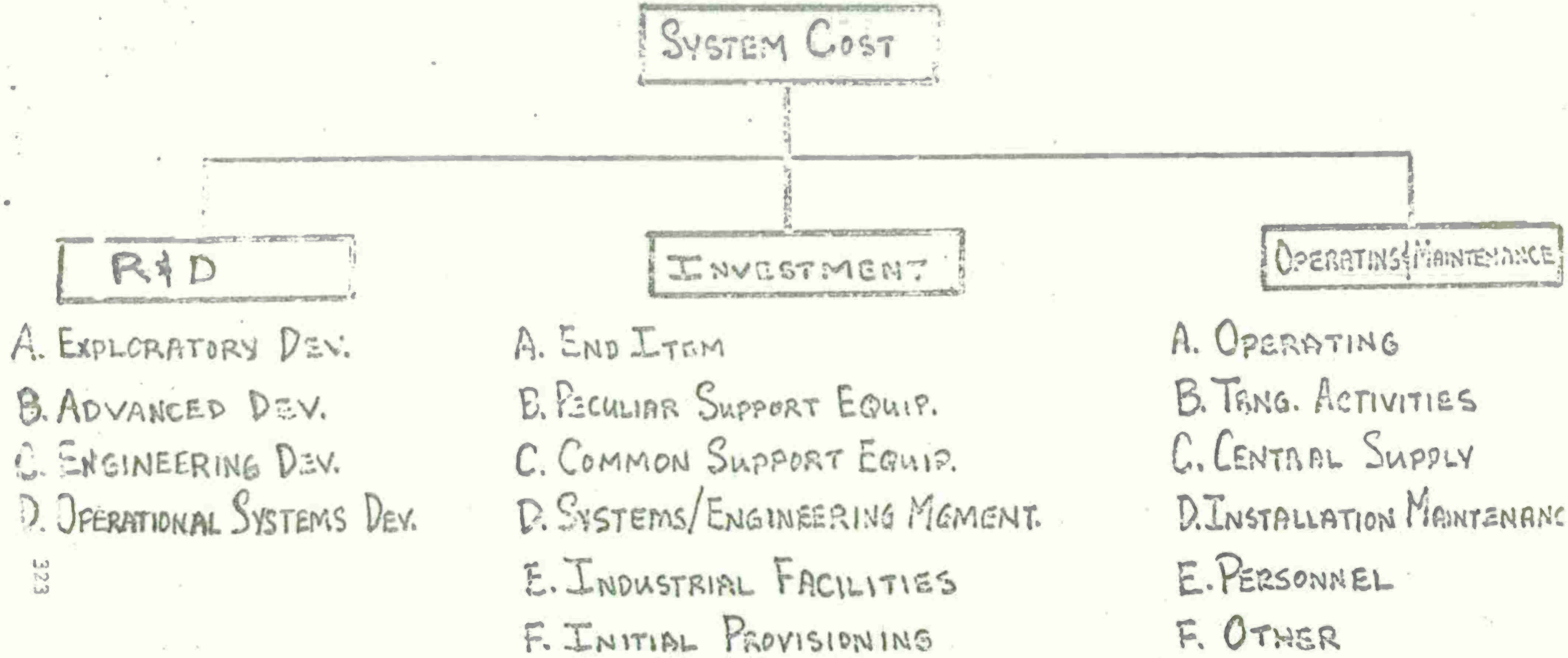

SYSTEM COST
R & D
A. EXPLORATORY DEV.
B. ADVANCED DEV.
C. ENGINEERING DEV.
D. OPERATIONAL SYSTEMS DEV.
INVESTMENT
A. END ITEM
B. PECULIAR SUPPORT EQUIP.
C. COMMON SUPPORT EQUIP.
D. SYSTEMS/ENGINEERING MGMENT.
E. INDUSTRIAL FACILITIES
F. INITIAL PROVISIONING
OPERATING & MAINTENANCE
A. OPERATING
B. TRNG. ACTIVITIES
C. CENTRAL SUPPLY
D. INSTALLATION MAINTENANC
E. PERSONNEL
F. OTHER

FIGURE 5

"Adjusting the Cost Discount Rate for Inflationary Trend"

by Horace Schow II, Major, U.S Army
Headquarters, U.S. Army Materiel Command

ABSTRACT

This paper discusses three methods of adjusting the cost discount rate for the inflationary trend of the economy. Theory and numerical examples are given. For typical values of interest and inflation rates it is shown, when the inflation adjusted cost discount rates are used in lieu of the standard discount rate (rate of return on capital), that a single ten-year uniform series program may have a discounted cost of up to 10 percent higher and that a comparison of two considerably spread six-year programs, made by subtracting the discounted cost of one from the other, results in a difference of 20 percent less.

Concerning cost-effectiveness analyses, E. S. Quade has said, "... it is seldom the mathematics or the computation that is questioned or at fault; almost always it is how we decide what assumptions to make, what contingencies to consider, what objectives to choose, what the costs and what the gains are, and, above all, it is the things we did not consider at all."[1] The general purpose of this paper is to bring to light and estimate the magnitude of one aspect of cost effectiveness analysis which usually is not considered at all.

The problem addressed here is that of comparing systems which have the same effectiveness, however that may be measured. A part of this comparison is the costing aspect. Usually the estimated future costs are expressed in terms of proposed funding programs which extend over several years. Sometimes a simple sum of programed costs of competing systems is sufficient. Another method is to compare the present equivalent cost or benefit of one program with another.

While the present value method may be applied to investment proposals in the sense that future earnings may be discounted from the future to the present, it will be assumed for the remainder of this paper that costs, and not

earnings, are being analyzed and that the term discount rate is used in the 'cost' rather than the 'earnings (benefit)' sense.

THEORY

The usual two-dimensional representation of a funding program has time (years) on the abscissa and costs (dollars) on the ordinate. The concept of inflation cannot be directly defined on this particular plane. The 'worths' of the units of the axes are necessarily invariant throughout the plane. Even though in the real world, assuming inflation, it is known that \$100 in year X is worth more than \$100 in year X + A, where A is positive, there is nothing on the year-dollar plane which admits this. Economists use the concept of utility to discuss the worth, satisfaction, or preference of one choice compared to another. Using a year-utile plane, where a 'utile' is a measure of utility, instead of the year-dollar plane allows the utility of the dollar to vary.

The well-known discounting process "expresses a value at any given date in terms of an equivalent value at some other date."[2] The present equivalent cost E(o) of a future cost E(n) at a time n years after the base date, assuming annual compounding, is

$$E(o) = E(n) / (1 + i)^n \qquad (1)$$

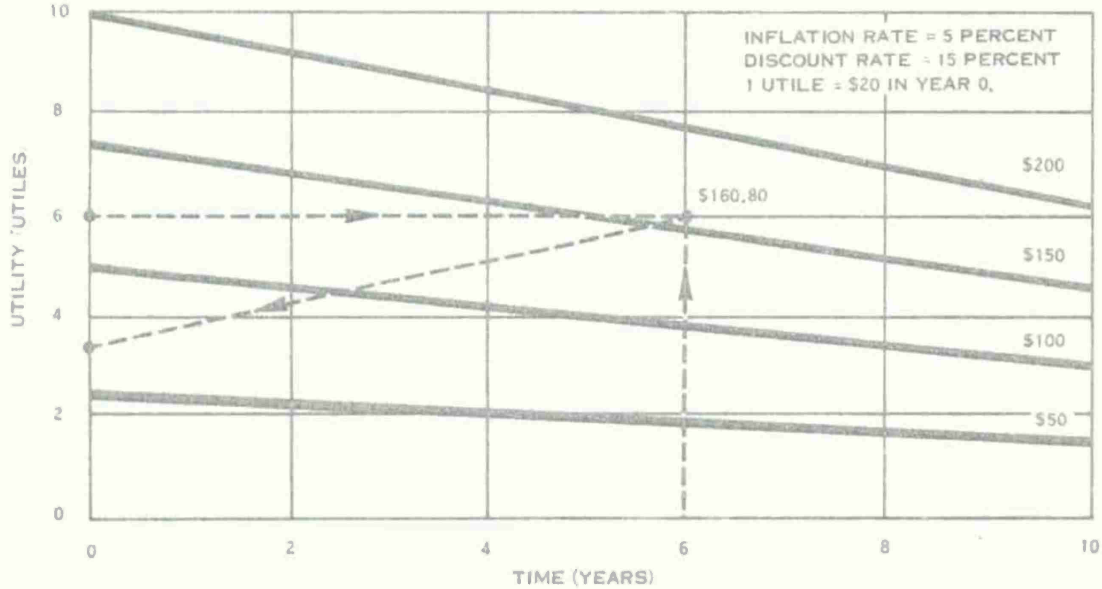
where i is the interest (discount) rate, sometimes called the rate of return on capital. It is said that the discounted cost of E(n) is E(o). Discounting is a specific unary operation where the domain is the funding program and the range is the discounted value of the program. The basic theory of discounting is discussed in references 3 through 8.

Equation (1) is usually applied directly to the year-dollar plane with the resulting comparisons of programs being made with dollars and not with the utility of the dollar amounts.

One general method of inserting the effect of inflation is to assign different utilities to the dollar ordinates. This may be done by adjusting the discount factor to take into account the interest rate and the inflation rate. The three methods given below do this. These methods are really comparisons made on the time-utility plane with the correspondence between the ordinates of the time-dollar and the time-utile planes being a time-dependent shrinking of the dollar.

On the time-utility plane the dollar parametric curves may be drawn. See Figure 1. These lines have a negative slope. For illustrative purposes let the inflation rate equal 5 percent, the discount rate 15 percent, and one utile \$20 in year 0. Assume the utility of a type of product is a constant 6 utiles throughout. In year 6 this product is worth \$160.80, which discounted to year 0 (Point A), is \$69.47. Had the dollar cost been assumed constant from year to year, the discounted amount would have been somewhat less than Point A. Numerical comparisons of this type of calculation will be given below.

THE TIME—UTILITY PLANE SHOWING THE CHANGE IN THE UTILITY OF THE DOLLAR WITH RESPECT TO TIME



IN YEAR SIX 6 UTILES ARE WORTH \$160.80, WHICH MAY BE DISCOUNTED TO POINT A IN YEAR 0. A = 3.47 UTILES = \$69.47.

FIGURE 1

The overall result of inflation is to increase the discounted cost of a time-phased program or, stated otherwise, to place a somewhat higher than usual present value on an expenditure made later on in time.

ADJUSTING THE COST DISCOUNT RATE FOR INFLATION

Method I. It may be argued that equation (1) is not realistic because of the inflationary trend of the economy. For illustrative purposes posit a discount rate i of 8 percent and an inflation rate r of 2 percent. Let n = 5 years. If E(o) = $100.00 then

$$E(5) = E(o)\ (1.08)^5$$

$$= \$146.93$$

But the worth of $100.00 in year 5 is less than in year o. It will take $100.00 $(1.02)^5$ = $110.41 in year 5 to purchase what $100.00 would in year o. The actual net growth of the $100.00, it may be argued, will not be $46.93 but rather $46.93 - 10.41 = $36.52. The variable discount rate v, which is a function of n, i, and r, may be expressed as

$$\$100.00\ (1 + v)^5 = \$136.52$$

$$v = 6.41 \text{ percent.}$$

For the general case

$$1 + v = \left[1 + (1 + i)^n - (1 + r)^n\right]^{1/n} \qquad (2)$$

or alternatively

$$1 + v = \left[1 + n\ (i - r) + \frac{n\ (n - 1)}{2\,!}\ (i^2 - r^2) \right.$$

$$\left. + \frac{n\ (n - 1)\ (n - 2)}{3\,!}\ (i^3 - r^3) + \ldots\right]^{1/n} \qquad (3)$$

It may be shown that v varies from v = i - r for n = 1 to v approaches i when n is very large.

Method II. One may also argue that rather than inflate the \$100.00 to year 5 it is more logical to deflate E(5) to year o. Thus in year o values E(5) is worth \$146.93/ $(1.02)^5$ = \$133.08 and

$$\$100.00\ (1 + d)^5 = \$133.08$$

$$d = 5.88 \text{ percent}$$

where d is the division discount rate.

For the general case

$$(1 + d)^n = (1 + i)^n \,/\, (1 + r)^n \tag{4}$$

$$1 + d = 1 + i - r - ir + r^2 + ir^2 - r^3 + \ldots \tag{5}$$

Equation (4) can be derived directly from the time-utile plane. Consider product A which has a utility of M utiles and N dollars in year o. Disregarding design obsolescence, product improvement, etc., the utility of A will continue to be M utiles in year n but the cost will rise to $N(1 + r)^n$ dollars. In year o the discounted cost of A is $N(1 + r)^n/(1 + i)^n = N/(1 + d)^n$ dollars which is the same result as equation (4).

Method III. Here it is argued that the previous two methods are too complicated and that the subtraction discount rate $s = i - r$ may be used without an essential difference. This assumes that only the first three terms on the right hand side of equation (5) are significant and that the sum of all terms to the right of these is approximately zero.

Numerical Examples

Two numerical examples will be used to examine the magnitude of the differences which arise by using each of the three methods. The first considers two programs of equal face values (undiscounted program totals) but having different distributions. The second example has equal yearly expenditures.

Example Number One

Let i = 8 percent and r = 2 percent. Figure 2 tabulates values of V, D, S, and I for n = 1 through n = 10 where

$$V = 1/(1 + v)^n \tag{6}$$

$$D = 1/(1 + d)^n \tag{7}$$

$$S = 1/(1 + s)^n \tag{8}$$

$$I = 1/(1 + i)^n \tag{9}$$

N	V(1)	D(2)	S(3)	I(4)
1	0.9434	0.9444	0.9434	0.9259
2	0.8881	0.8920	0.8900	0.8573
3	0.8344	0.8424	0.8396	0.7938
4	0.7824	0.7956	0.7921	0.7350
5	0.7325	0.7514	0.7473	0.6806
6	0.6846	0.7097	0.7050	0.6302
7	0.6389	0.6702	0.6651	0.5835
8	0.5955	0.6330	0.6274	0.5403
9	0.5544	0.5978	0.5919	0.5002
10	0.5155	0.5646	0.5584	0.4632

(1) $V = (1+V)^{-N}$ VARIABLE DISCOUNT FACTOR
(2) $D = (1+D)^{-N}$ DIVISION DISCOUNT FACTOR
(3) $S = (1+S)^{-N}$ SUBTRACTION DISCOUNT FACTOR
(4) $I = (1+I)^{-N}$ INTEREST DISCOUNT FACTOR

WHERE

V = VARIABLE DISCOUNT RATE; SEE EQUATION (2)

D = DIVISION DISCOUNT RATE; SEE EQUATION (5)

S = SUBTRACTION DISCOUNT RATE = I − R

I = INTEREST RATE = 8 PERCENT

R = INFLATION RATE = 2 PERCENT

FIGURE 2

Consider the two hypothetical programs A and B. Figure 3 gives cost magnitudes and distributions. Figure 4 gives the discounted costs of the two programs using the four discount factors. The calculation, for example, of Program A discounted to year o using the variable discount factor V is

$$A = 50.00\ (1.0000) + 500.00\ (0.9434)$$

$$+ 400.00\ (0.8881) + 20.00\ (0.8344)$$

$$+ 10.00\ (0.7824) + 10.00\ (0.7325)$$

$$+ 10.00\ (0.6846)$$

$$A(V) = 915.62 \text{ kilodollars}$$

V, D, and S differ in the discounted cost of A by about 0.3 percent and of B by 3.0 percent. As a whole V, D, and S discount A about 3 percent higher than I and B about 9 percent higher.

HYPOTHETICAL PROGRAM A AND B

YEAR N	PROGRAM* A	PROGRAM* B
0	50	--
1	500	10
2	400	10
3	20	10
4	10	20
5	10	400
6	10	500
7	--	50
	$1000	$1000

* COSTS IN THOUSANDS OF DOLLARS.

FIGURE 3

DISCOUNTED VALUES OF PROGRAMS A AND B
DISCOUNTED COSTS OF PROGRAMS USING DISCOUNT FACTOR:
(THOUSANDS OF DOLLARS)

PROGRAM	I	V	D	S
A	892.20	915.62	918.42	916.94
B	656.98	709.55	731.62	727.25
(A—B)	235.22	206.07	186.80	189.69

FIGURE 4

Example Number Two

Consider a project which has programed ten million dollars per year for ten years. What will be the discounted cost of the entire program? Figure 5 gives the discounted costs using all four discount factors with i = 8 percent and r = 2 percent. The use of the adjusted discount factors

DISCOUNTED COST OF PROGRAMS
THE PROGRAM CALLS FOR THE EXPENDITURE OF $10 MILLION PER YEAR FOR 10 YEARS.

DISCOUNT FACTOR USED*	DISCOUNTED COST OF PROGRAM (10^6\$)	PERCENT GREATER THAN I VALUE (PERCENT)
D	74.01	10.30
S	73.60	9.69
V	71.70	6.86
I	67.10	-- --

*I = 8 PERCENT AND R = 2 PERCENT

FIGURE 5

results in a discounted program cost of about 7 to 10 percent higher than that discounted with no adjustment for inflation.

Varying interest and inflation rates

Figures 6 and 7 show the effect of varying the interest rate i and the inflation rate r with n fixed at seven years. The standard interest discount factor I is used for comparison purposes. The inflation rate r was 2 percent in Figure 6 and 5 percent in Figure 7. These figures show that all three of the adjusted discount rates discount higher than the standard I and that the percentage increases with increasing r. The percentage differences are a maximum of about 15 percent for r = 2 percent and rise to a maximum of 40 percent for r = 5 percent. The discounted values using S do not change much from those using D. The V values generally are about halfway between I and S when compared on a percentage basis.

COMPARISON OF ADJUSTED DISCOUNT FACTORS
WITH n=7 YEARS & r=2 PERCENT

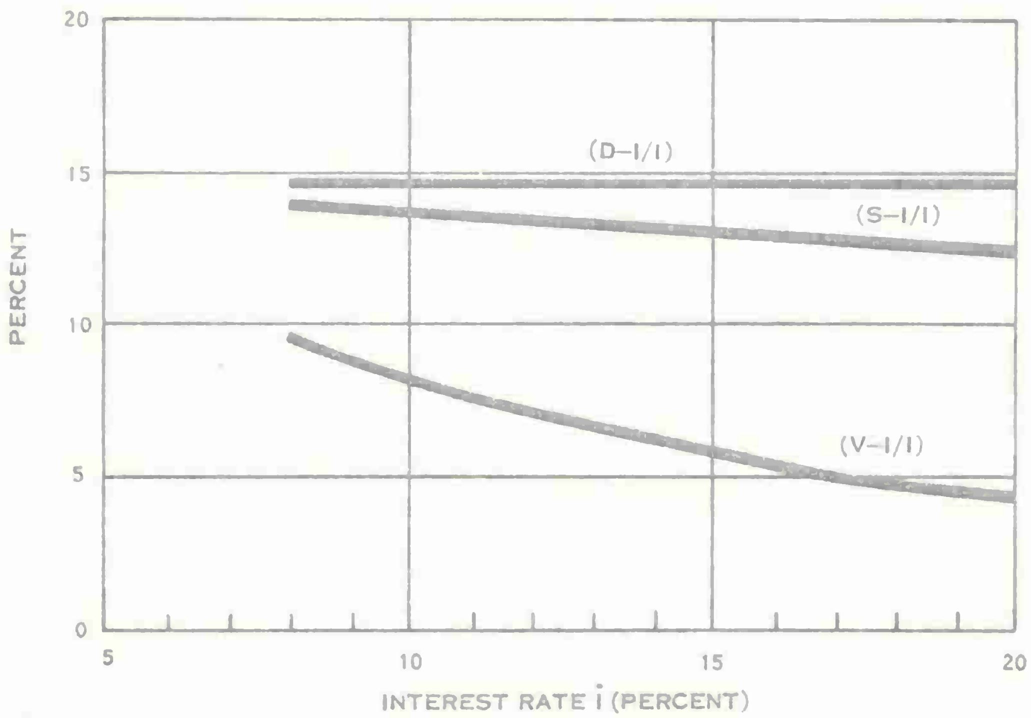


FIGURE 6

COMPARISON OF ADJUSTED DISCOUNT FACTORS
WITH n=7 YEARS & r=5 PERCENT

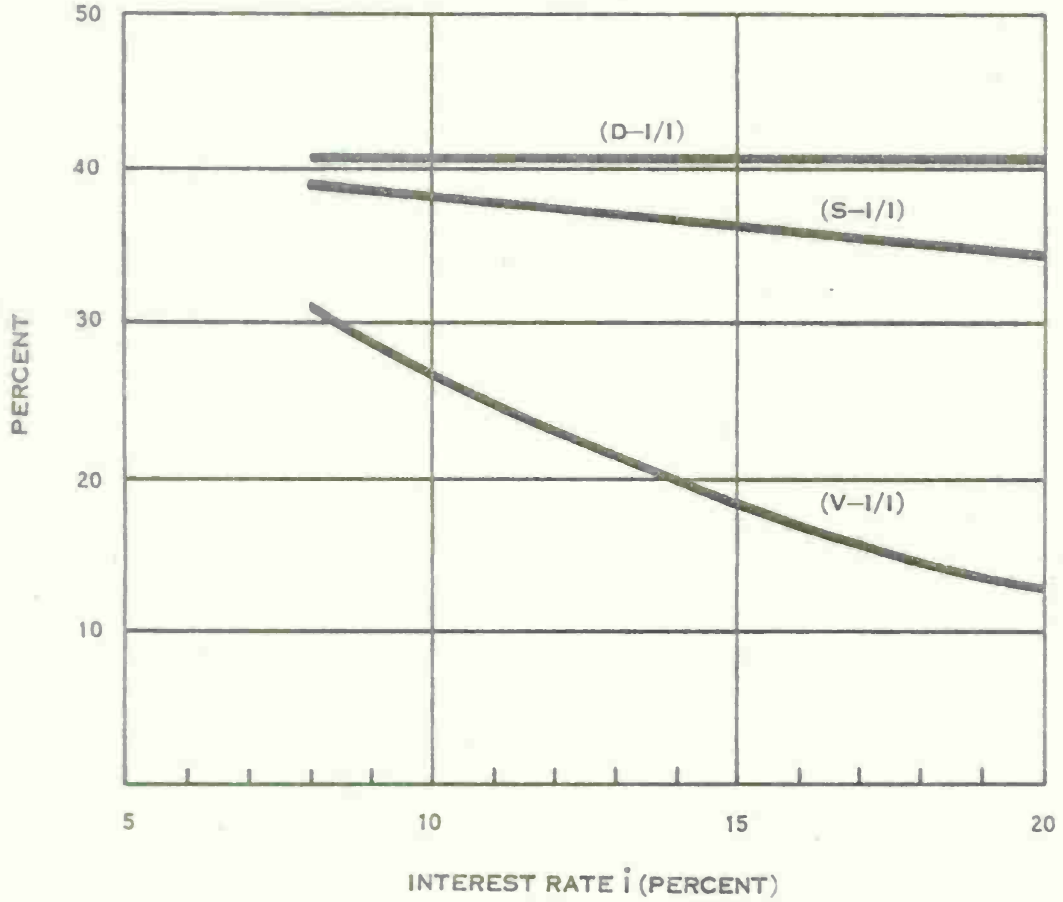


FIGURE 7

CONCLUSIONS

The use of the inflation adjusted cost discount rates (factors) results in higher discounted total program costs by about 0.3 to 10 percent. It was shown for the case when n = 7 years that the difference in the discount factors when compared to the standard interest discount factor ranges from 4 to 15 percent when the inflation rate r was 2 percent to 12 to 40 percent when r was 5 percent. When comparing two programs by subtracting the discounted cost of one from the other, the use of an inflation adjusted discount rate, rather than the standard rate, can result in a difference of up to 20 percent less.

Of import is the realization that the changes in discounted program costs (or comparisons between two alternatives) brought about by the use of the inflation adjusted discount rates are of the 10-30 percent magnitude and that the decision as to which discount factor, interest rate, or inflation rate to use, made either deliberately or subconsiously, may be significant. To achieve full control of the analysis the decisions bearing on these factors and rates should be visible and deliberate. If the analyst is uncertain or if company policy gives no specific guidance, then the discounted costs of the alternatives may be computed using the several rates and the range of costs presented to the decision maker.

The final choices as to which inflation rate and specific discount factor to use are dependent upon the philosophy used for the initial selection of the interest rate. There clearly are no patent "best" constant selections. In light of the rather large uncertainty in the estimate of the appropriate interest rate and the relatively small differences between discounted costs it would appear that the subtraction discount factor, the most easily obtained, recommends itself and that the slightly more complex variable and division rates are unnecessary.

In the Systems Analysis Branch of Headquarters, U.S. Army Materiel Command, whenever program comparisons are made, the interest rate (rate of return on capital) of 15 percent and inflation rate of 5 percent are assumed. The subtraction discount factor is used. Reference 8 discusses the recommended discount rate for military usage. Also see reference 9.

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SYSTEM ANALYSIS OF VEHICULAR RIVERINE EGRESS

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Frequency, distribution and characteristics of rivers in diverse world terrains are described in terms of riverine egress ability of Army vehicles. Actual vehicle tests in rivers are described, quantified and illustrated. Mathematical expressions are developed which predict vehicle capability in river egress, such that a foundation is laid for systems analysis treatment. A specific analytical routine is proposed, applicable to a wide spectrum of the present day Army vehicle fleet and design projections into the future are presented, which permit optimuming vehicle design for river egress.

I. INTRODUCTION.

What does a river mean to you? To a lover, romance; to a photographer, scenery; to a historian, an avenue of civilization; to an explorer, a route into the unknown; but to the Army, a river is a barrier obstructing the advance of vehicles (Fig 1).

For a decade the Army has been seriously coping with the problem of crossing rivers in vehicles, sometimes wading or deep fording, or swimming specially designed buoyant, self-propelled types. However, despite these efforts the river problem has never been fully defined and solutions have not been sought in a systematic way.

In an effort to define the problem the U. S. Army Tank-Automotive Command has made a limited study of rivers in various parts of the World to identify in quantitative terms what the significant variables are, how they can be measured and how these numbers can be used to improve riverine capability in new vehicle design. Information derived from this study has been blended with vehicle design thinking into a systems analysis where the vehicle, the river and the ground surrounding the river are considered as quantified elements of a single coherent pattern. We conclude that substantial vehicle design steps can be taken so that rivers will no longer be barriers.

II. DEFINITION OF THE PROBLEM.

A military requirement that combat and tactical use vehicles have inherent water crossing capability has existed for some years. Most of the research and development work in support of this requirement evolved around specialized fording kits for the non-swimmers and schemes and devices to improve water speed for the amphibians.

With this background, a systems analysis which followed a conventional pattern might have developed like that shown in Fig 2. An expansion of this analysis is shown in Fig 3. The major emphasis in this analysis is on water. The assumption has been made that water "depth, width, and velocity," are the prime reasons that a river is a barrier.

Past experience dictated caution and since there are all types, shapes, and manner of rivers in the immediate area, it was decided to make a quick survey of the surrounding Michigan and Ohio areas to document the hypothesis that water was the problem.

The results of this survey were that most of the rivers surveyed were not very big or very deep. Statistically, the survey covered 1,030 miles and surveyed 90 rivers, 83% of which had a wetted surface width of less than 100 feet and an average depth of less than 3.5 feet (Figs 4 & 5). In Michigan a river was encountered an average of every 13.5 miles and every 9.6 miles in Ohio.

The results of the survey, plus contact with the British Military Experimental Equipment Establishment at Christchurch, who stated that they were primarily concerned with getting the vehicles out of the river, rather than getting them across, prompted the planning of a more extensive survey.

The resulting survey was conducted along the 43° and 36° north latitudes in the United States. A physical survey was conducted, rather than attempting map analysis, photo interpretation, or analysis of hydrologic records, because this was the only way all of the required information could be obtained and because it was a fast, economical method. The two teams covered the 6,365 miles required to make the survey in three weeks (Fig 6). In all, 276 rivers were surveyed; 64% were less than 100 feet wide and had an average depth of less than 3.25 feet; 75% were less than 150 feet wide and had an average depth of less than 5.35 feet; 75% were less than 150 feet wide and had an average depth of less than 5.35 feet (Figs 7 & 8). The significance of the low water depth is that, if a river is less than 3 or 4 feet deep, its width is immaterial, all other things being equal.

There were significant differences in river frequency between the Eastern and Western United States. In the eastern United States, there was a definite water crossing problem; a river was encountered every 14 miles, and in the western United States, where a river was encountered once every 40 miles, there was not. Consequently, most of the subsequent analysis was done with the eastern United States data.

With river width and depth ruled out as the prime reason for a river being a barrier, the river profile and bank data were carefully examined. The analysis showed that in the eastern United States 60% of the banks had a slope or vertical step that a military vehicle would not normally be expected to negotiate. Therefore, after traveling 7,395 miles and surveying 348 rivers, it was concluded that the prime reason that a river is a barrier is that the majority of the river banks are so geometrically severe with respect to the normal military vehicle obstacle or slope performance capability that the vehicle is unable to exit from the river (Fig 9).

There are factors other than bank geometry to be considered and, of course, in 25% of the rivers the water is deep and swift enough to cause difficulty in water crossing. However, it was felt that the first thing that should be attempted was to analyze the exiting problem because it appeared to be the single most important problem that must be solved if amphibious vehicles were to cross rivers.

III. ANALYSIS OF EXITING PERFORMANCE.

The basis of the river exiting study was to relate a mathematical model of the river bank to a mathematical model of vehicle performance (Fig 10). The river bank model was based on the environmental data that was obtained on the surveys. The vehicle performance model was based on test reports and calculated data.

The systems analysis that was conducted to date indicates two choices: modify the environment, or modify the vehicle. The "modification" involved may not have to be as severe as that shown in Fig 10. USATACOM is exploring a number of ideas, but as yet no clear-cut solution for providing a 100 percent water crossing capability has been evolved.

The elements, the systems analysis, the mathematical models of the river bank and vehicle performance, were developed on a semi-empirical basis.

A number of bank profiles from the survey data were examined and it was concluded that some method of expressing the severity of the bank with respect to some known vehicle performance measurement was needed. After several attempts, the idea of expressing the bank geometry as an equivalent vertical step was evolved (Fig 11). Vehicle obstacle performance was, therefore, expressed as its ability to negotiate a vertical wall.

Computation of the equivalent vertical step is accomplished with an empirical relationship:

$$\text{Equivalent step} = (\text{height of bank}) \times (\text{Sine of bank slope angle})^2$$

As indicated in Fig 12 the bank geometry can be represented by a series of steps and average slopes and the individual parts summed. The analysis consists of a comparison between the equivalent vertical step that the bank represents and the vertical wall that a vehicle can negotiate. For example, if the vehicle can negotiate a 3 foot vertical step and the equivalent step height for the river bank is $2\frac{1}{2}$ feet, the vehicle will go.

Vehicle performance differs in negotiating a solid, wood or concrete vertical step and a near vertical earth step. The vehicle can often, but not always, negotiate an earth step two or three times higher than a solid step. This range of uncertain performance is referred to as MARGINAL in the analysis and represents those cases where the vehicle can at times negotiate the bank by bulldozing and/or excavating with its tracks or wheels (Fig 13).

To conduct an analysis it must be determined, by testing or calculation, the solid step that the vehicle can always climb, which is the upper limit of the GO value and the maximum height of a vertical earth step that the vehicle can probably climb, which is used as the upper limit of the MARGINAL value. Above this latter height, the vehicle is judged to have NO-GO capability.

The results of such an analysis for an M-113 Armored Personnel Carrier (Fig 14) for sites surveyed in the eastern United States showed that the vehicle:

Would GO - 26% of the time,

would have MARGINAL success - 16% of the time,

and would <u>not</u> GO - 58% of the time.

For Thailand, the analysis showed that the vehicle:

Would GO - 22% of the time,

would have MARGINAL success - 26% of the time,

and would <u>not</u> GO - 52% of the time.

IV. PROBLEMS IN DEVELOPING A MORE SOPHISTICATED ANALYSIS.

Work is in progress to develop a more comprehensive, and hopefully a more accurate analysis. The biggest impediment is trying to describe, in engineering numbers, what has been observed on field tests.

The first field test was conducted in the Clinton River, about 15 miles from USATACOM. The Clinton River is small, varying from about 20 to 50 feet wide. No difficulty was anticipated. The purpose of the exercise was to observe how the vehicle egressed from the river.

In a short time the vehicle became hopelessly immobilized (Fig 15). A wrecker, using a 25,000 lb winch and a three part cable was required to recover the M-113 (Fig 16). Inadvertently a spot had been picked where the water slowed down, and the silt carried in suspension settled out, creating a mud bog. Any time the water velocity slows down at the outside of a bend in a river, a delta at the mouth of a river, or even a canal, the soil carried by the water settles out creating an exiting problem for amphibious vehicles.

In the Fall of 1967, exiting tests were conducted in Alaska where a different problem was found. The river beds in Alaska are primarily rock and gravel, soft soil is hard, but not impossible to find.

The most important thing learned from this exercise was how vehicles exit. Vehicles build themselves a ramp to get over the bank. They do this by bulldozing the bank lip or excavating with the tracks (Fig 17). If the vehicle cannot do this, even a low 4 ft bank will pose an insurmountable problem. Subtile differences, such as a 12 vs a 6 inch root depth of grass covering the top of the bank can mean the difference between a GO and NO-GO condition. This means that vehicle performance, while on that type of grass, in that type of soil will be measurable. Performance predictions cannot be made for a bank having some other type of weed in the same soil, or for a different vehicle (Fig 18).

In the analysis this problem has been avoided by calling such cases MARGINAL. It is hoped that future evaluations can be made more definitive. However, this is only one of perhaps a dozen examples that could have been chosen relating to the river bank alone. If the driver is included as the Cornell Aeronautical Laboratory Study is now doing in their mobility analysis, the problem becomes even more complex.

USATACOM has two unique facilities which will provide some of the inputs required for a realistic analysis. The first of these is the river simulation facility of the Land Locomotion Laboratory (Fig 19). This facility has been used to determine how military amphibious vehicles develop traction on river banks.

A 1/6 scale model of an M-59 armored personnel carrier was towed up a suspended ramp, which represents the river bank. The normal, tangential, and towing forces are measured as functions of the vehicle travel up the bank. The study showed that the tracked vehicle will apply traction forces to the bank in a uniform manner (Fig 20). There is some tendency for the vehicle to "Bridge" between the water and the bank, causing a higher than normal ground pressure during the first half of the exiting process.

The test was repeated with a 1/4 scale model of a 5-Ton 8x8 truck, the XM-453. The truck does not apply traction forces gradually. The leading axle must provide approximately 50 percent, versus a normal 25 percent, of the tractive effort if the vehicle is to exit. There is a definite "Bridging" between the portion of the vehicle in the water and the leading axle, which produces the load concentration.

It was known before the test series was initiated that a tracked vehicle was superior to a wheeled vehicle as far as river exiting was concerned. The new knowledge we have obtained is <u>why</u> the tracked vehicle is better; -- it applies its load to the soil in a <u>uniform manner</u>, and <u>how</u> -- by virture of its suspension system, which has a high degree <u>of</u> compliance with the bank slope. Fig 21 shows the test setup used to show the exiting performance data.

As a result of the model test work, an equation which will describe exiting ability in terms of the vehicle suspension system, weight, center of gravity location, and hull configuration can now be developed.

Another unique device we plan to utilize is the Land Locomotion Division Track and Wheel Dynamometer (Fig 22). This newly installed device permits accurate measurements of the traction developed by full size tracks or wheels under a wide range of normal loads, relative slip, and soil conditions.

By relating this information to the model data from the river simulator, an accurate mathematical prediction of exiting capability can be formulated.

On other environmental type projects it was found that nature was repetitive. The river surveys indicate that some aspects of the river's environment are repetitive. For example, an important river parameter is the wetted surface width of the river. A comparison of the distribution of widths in the eastern United States, Germany and Thailand shows a remarkable similarity (Fig 23).

V. USE OF ENVIRONMENTAL DATA FOR AMPHIBIOUS VEHICLE DESIGN.

The approach being used to utilize the riverine data for design purposes is to evaluate new concepts using the equivalent obstacle method previously described. This evaluation gives a prediction of the percent of the river banks in the survey area that the vehicle could exit, based on the vehicles inherent exiting capability. Additional evaluations are made of the estimated exiting performance if the vehicle were equipped with a self-recovery device. Such a device would provide the additional pull, or thrust, needed to negotiate the bank.

To provide realistic guidance for the designer it is necessary to provide a description of the bank the vehicle is expected to negotiate. For example: one analysis shows that a concept vehicle would negotiate 48 percent of the river banks in the Eastern United States if it was equipped with a self-recovery device that would provide an additional pull, or thrust, of 25 percent of the G.V.W. From the survey data, the bank which would correspond to the upper limit of this capability was found to be either:

a. A 6½ foot near vertical bank.

b. A 45 degree slope 12 feet high.

It had been hoped that a single bank could be specified, but the survey data showed that both types, the step and the slope seem to occur with

approximately the same frequency; hence, both were specified to the designer as being representative of what the vehicle would encounter.

A limited set of soil conditions were also specified. These were based on survey data and observations. They included:

a. The vegetative cover on the bank or slope.

b. Soil cohesion.

c. Soil internal friction angle.

With this information it is possible for the designer to develop a realistic picture of what the vehicle mobility requirements for river exiting will be.

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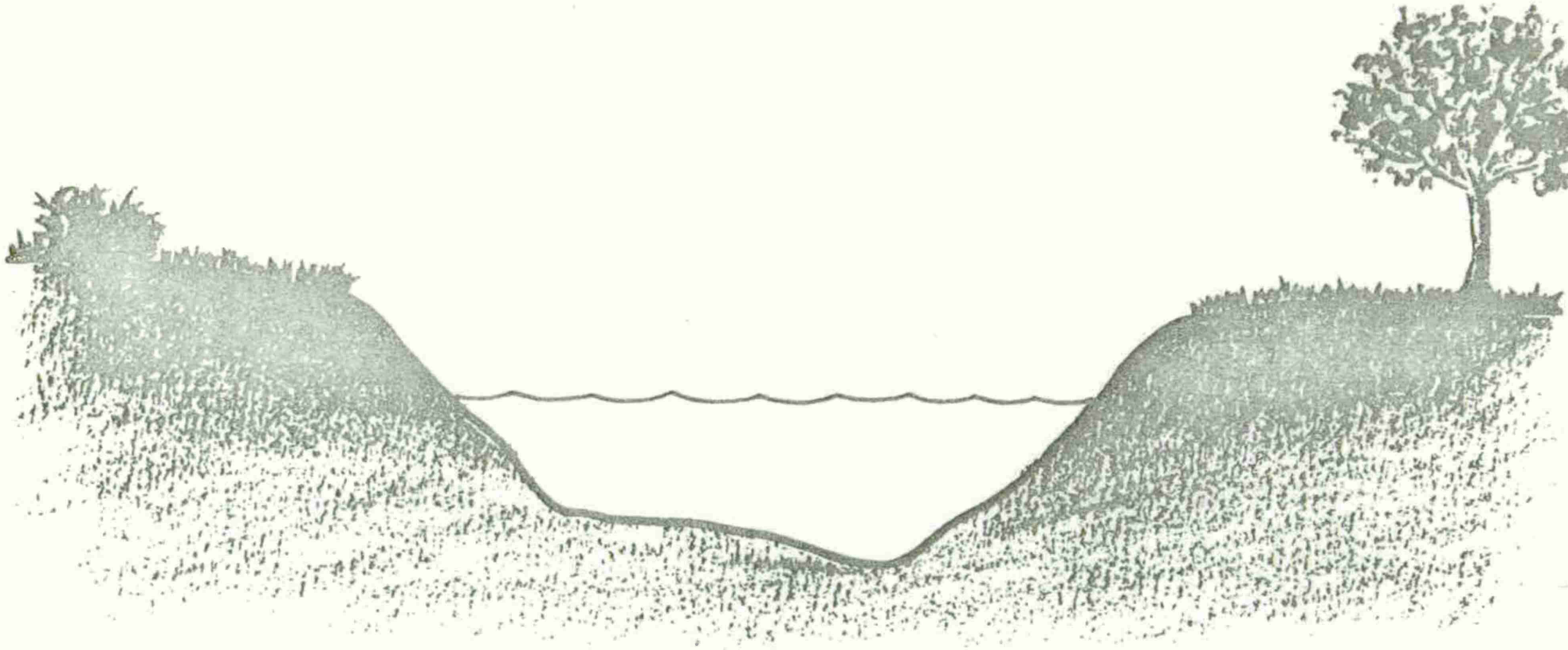
RIVER CROSSING MEANS:



DRY BANK → TO → DRY BANK

FIG. 1

PROBLEM STATEMENT

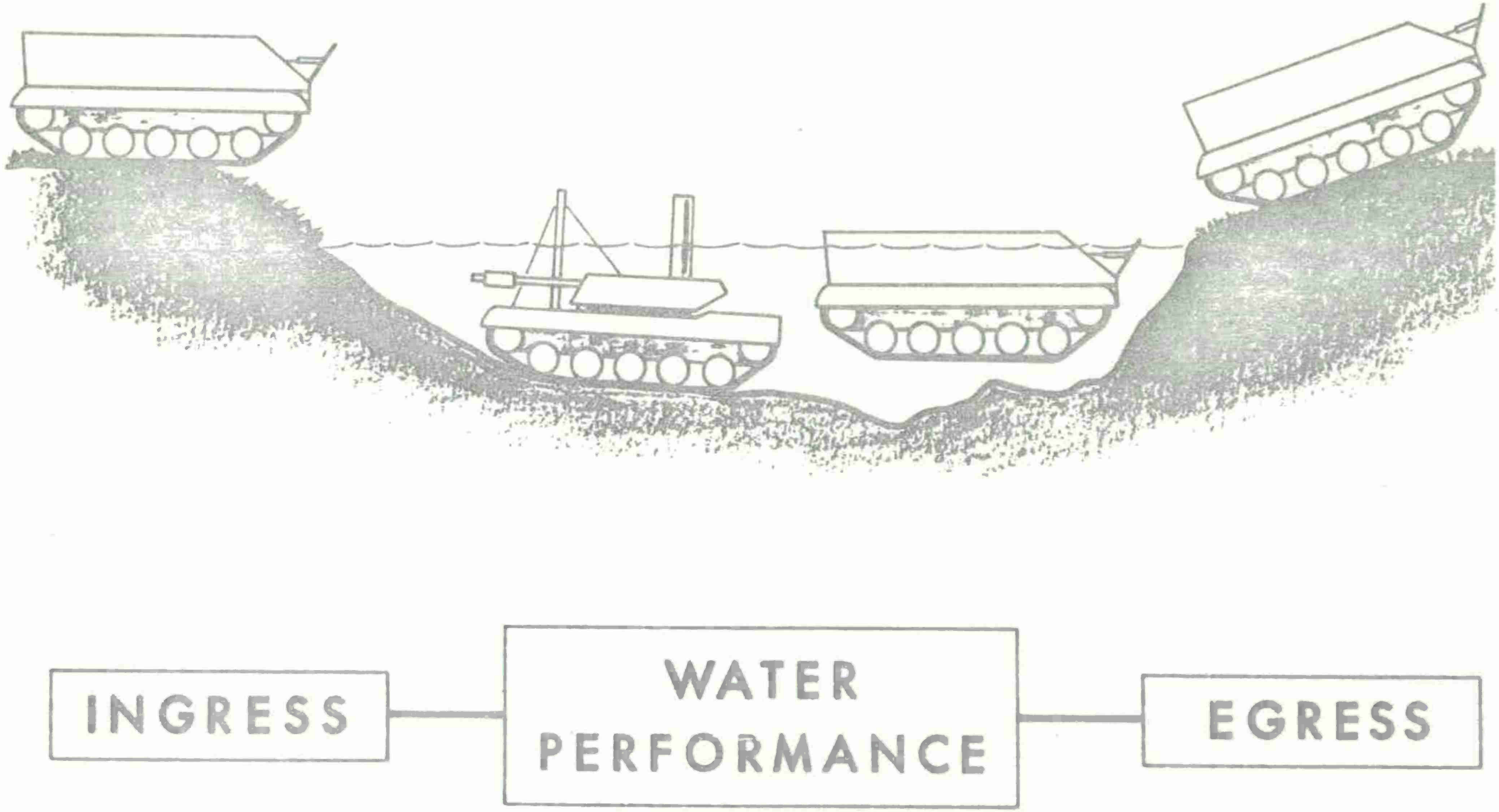


FIG. 2

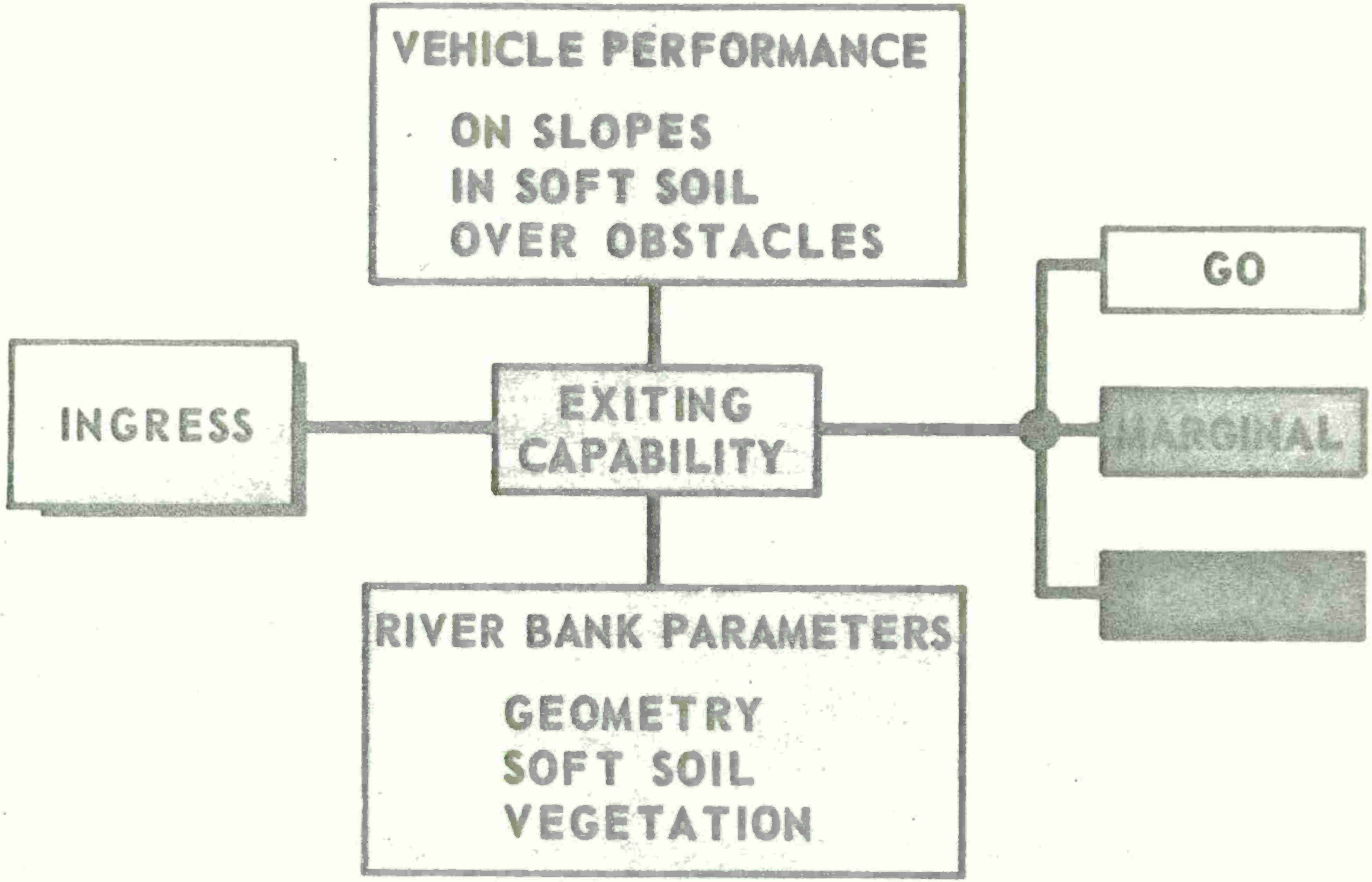

VEHICLE PERFORMANCE
ON SLOPES
IN SOFT SOIL
OVER OBSTACLES
INGRESS
EXITING
CAPABILITY
GO
MARGINAL
RIVER BANK PARAMETERS
GEOMETRY
SOFT SOIL
VEGETATION

FIG. 3

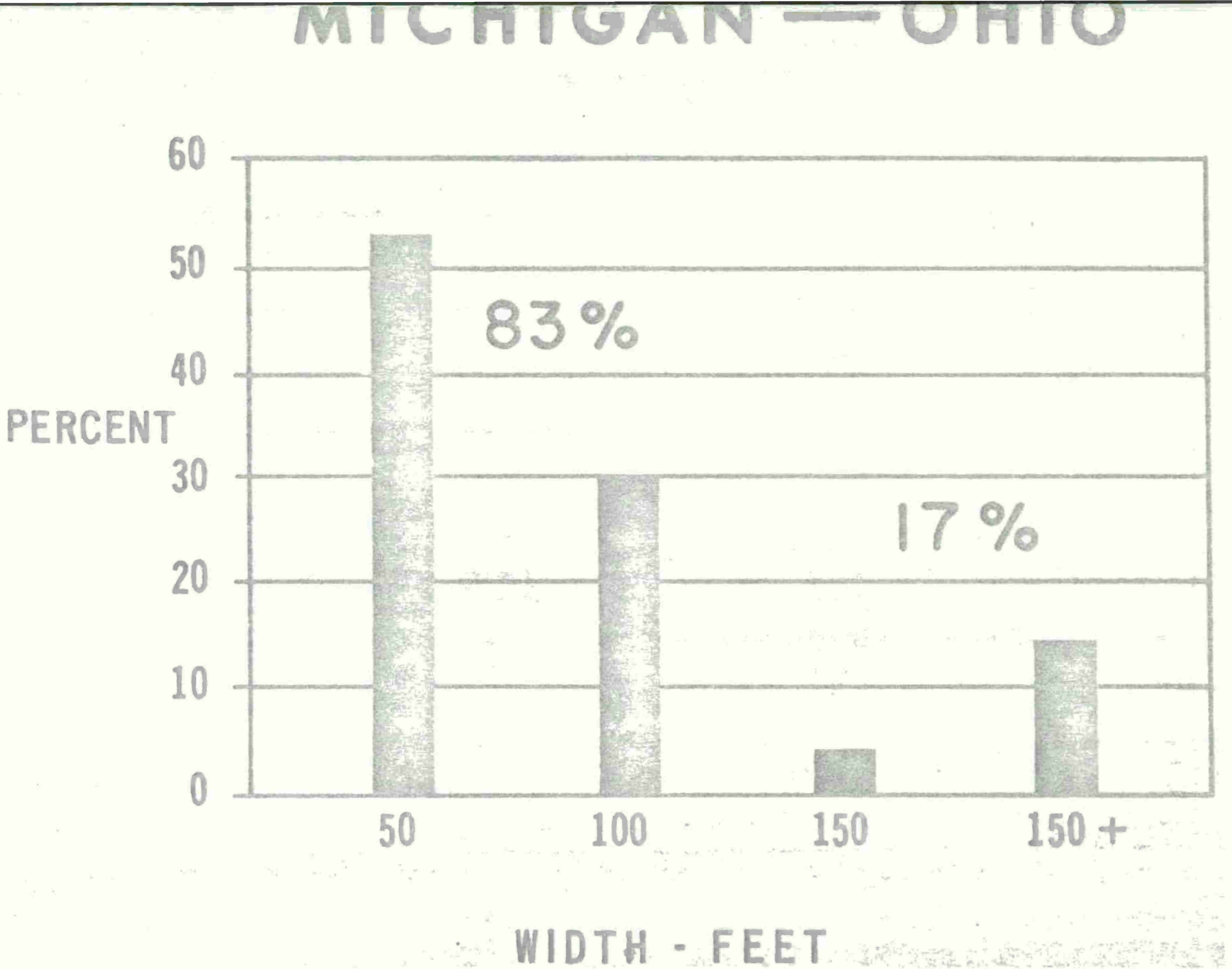
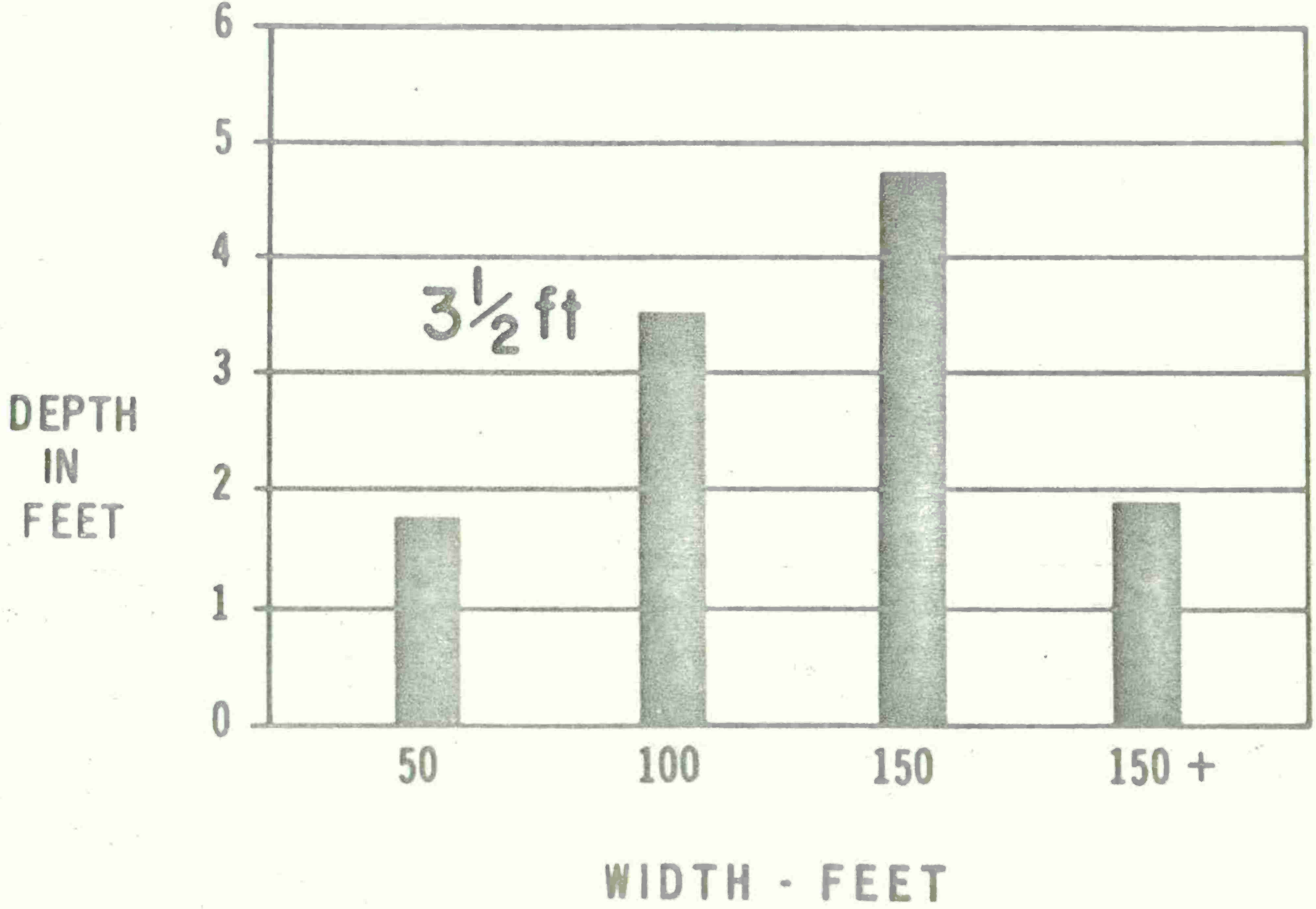

MICHIGAN — OHIO
60
50
40
30
20
10
0
PERCENT
83%
17%
50
100
150
150 +
WIDTH - FEET

FIG. 4

MICHIGAN — OHIO



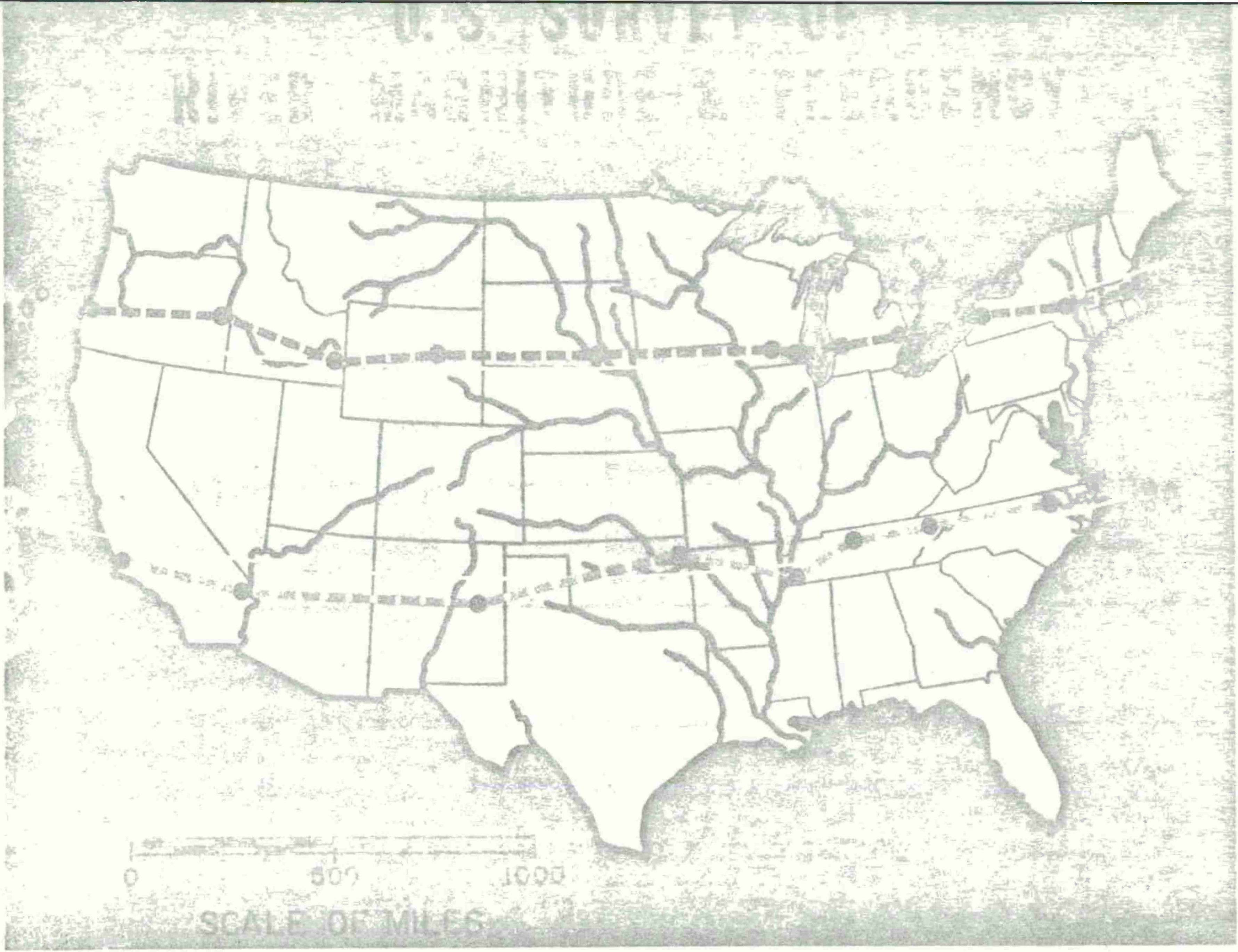
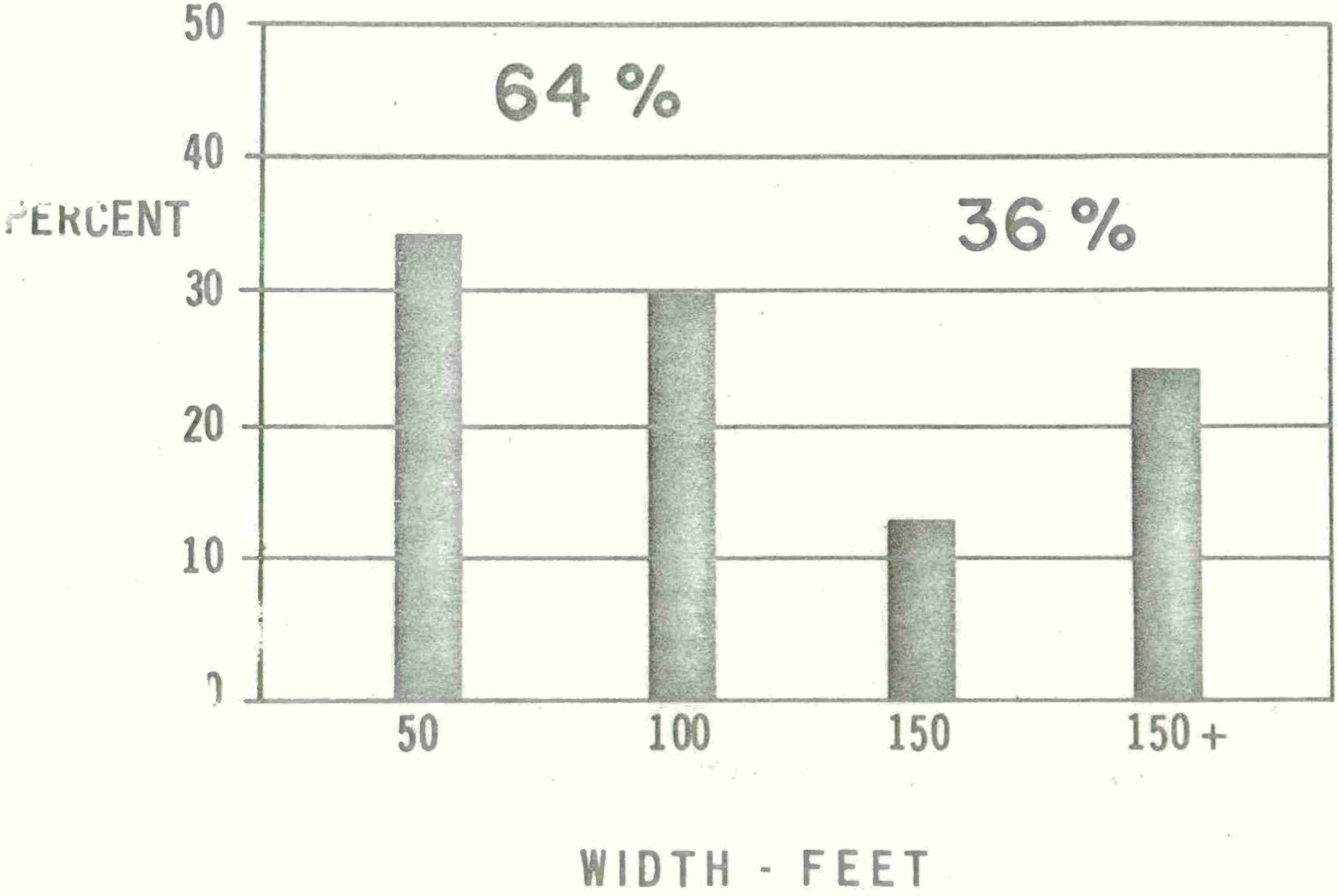


FIG. 6

UNITED STATES



UNITED STATES

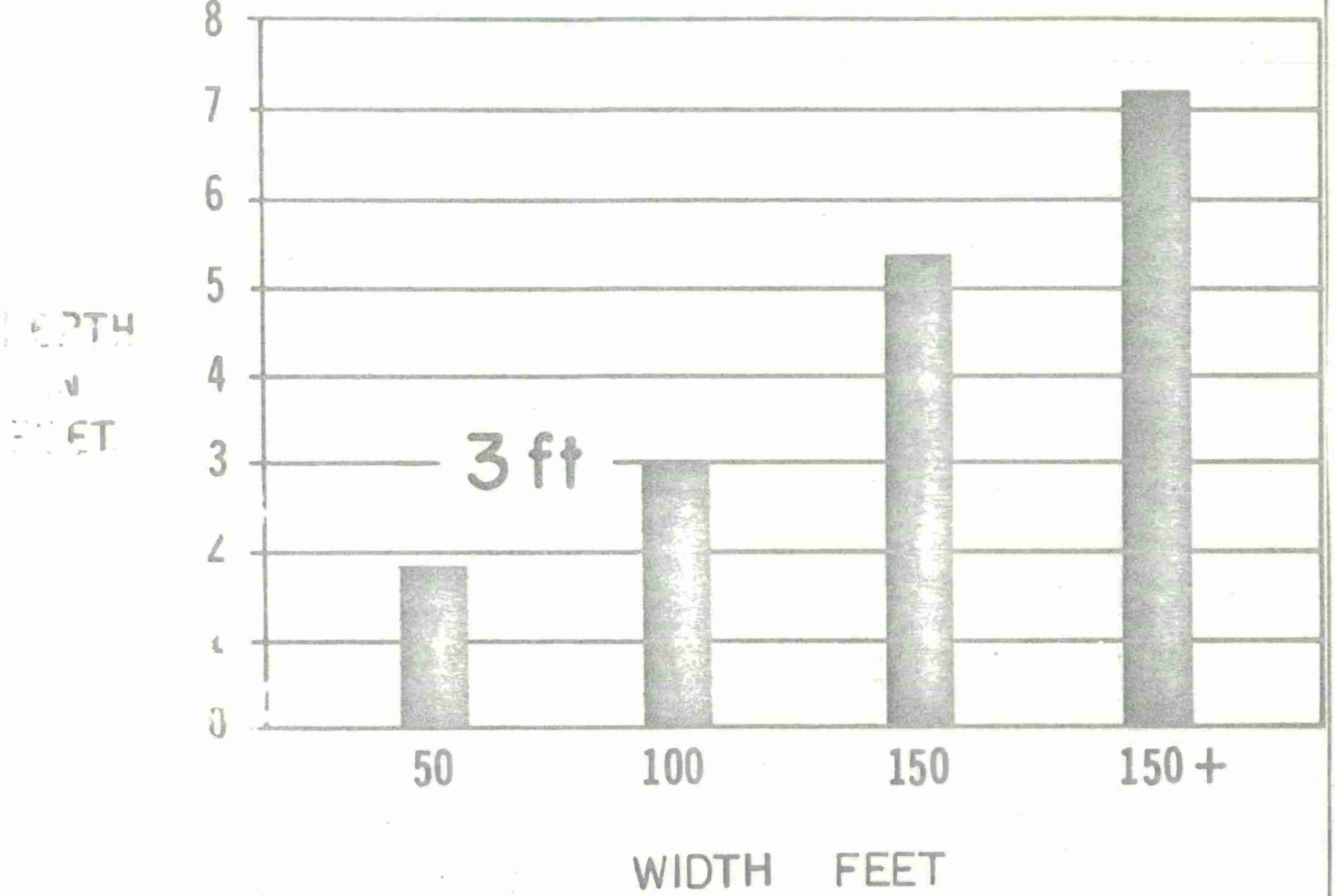
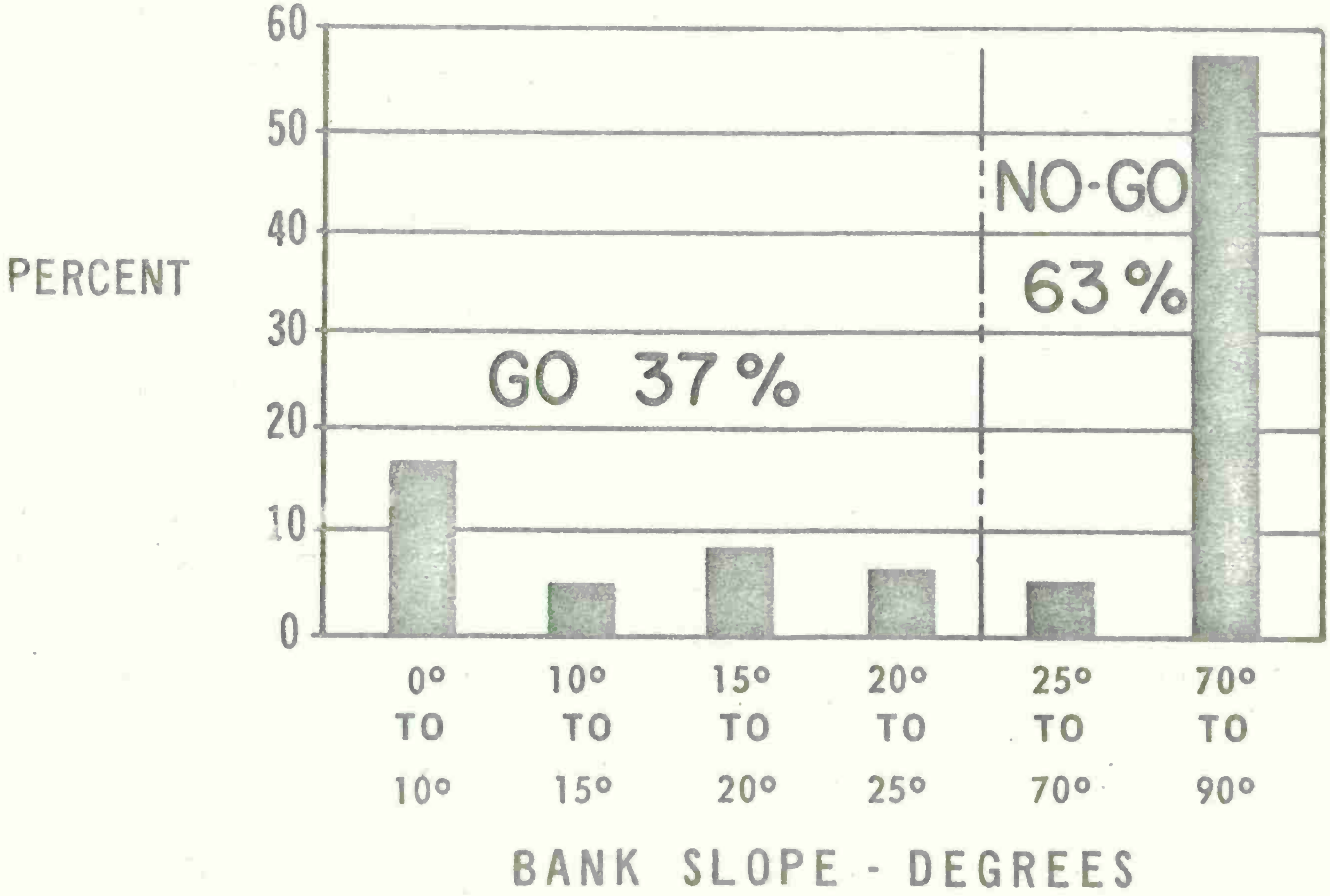


FIG. 8

EASTERN U.S.



60
50
40
30
20
10
0
PERCENT
NO-GO
63%
GO 37%
0° TO 10°
10° TO 15°
15° TO 20°
20° TO 25°
25° TO 70°
70° TO 90°
BANK SLOPE - DEGREES

RIVER EXITING STUDY

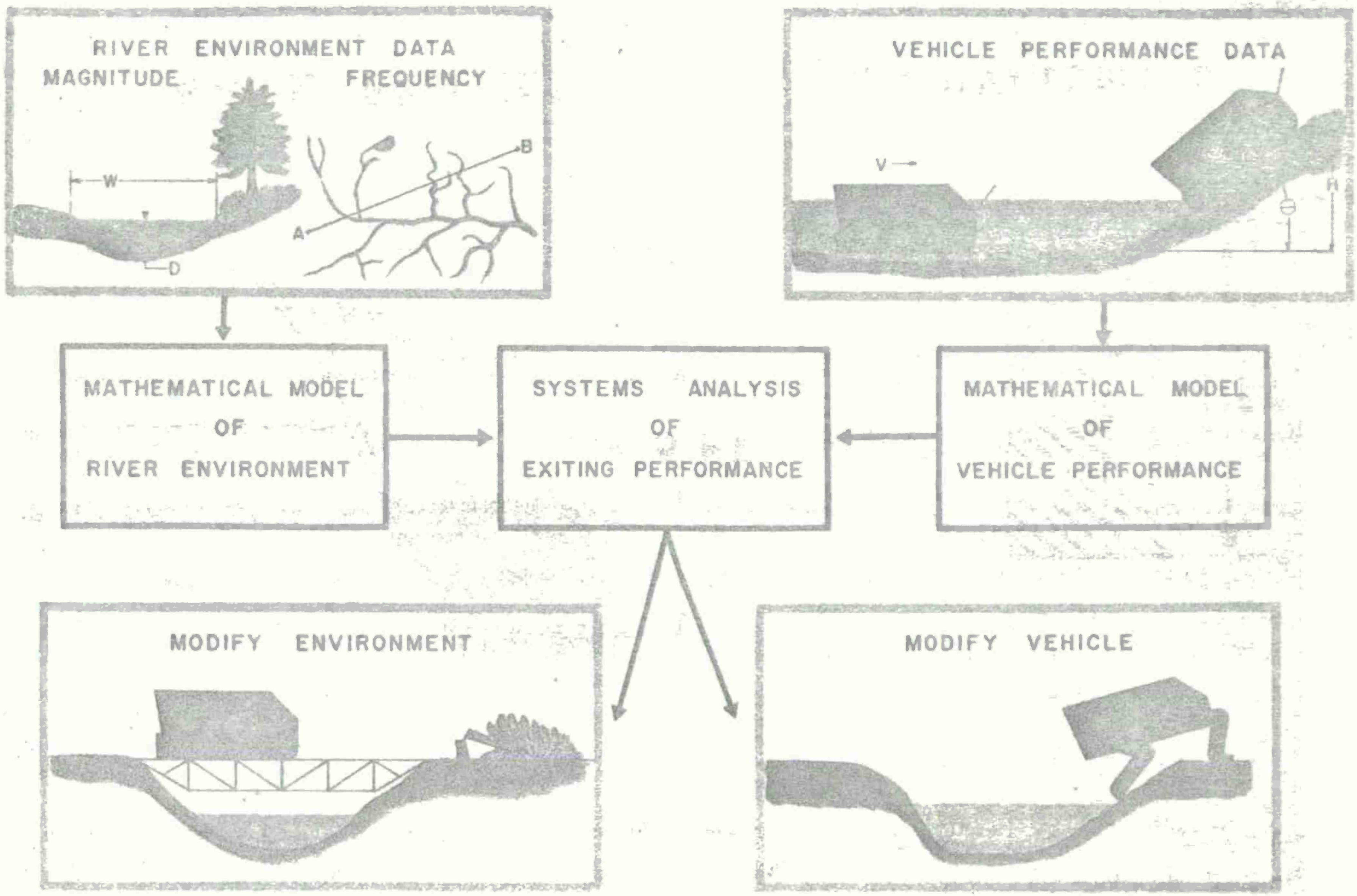
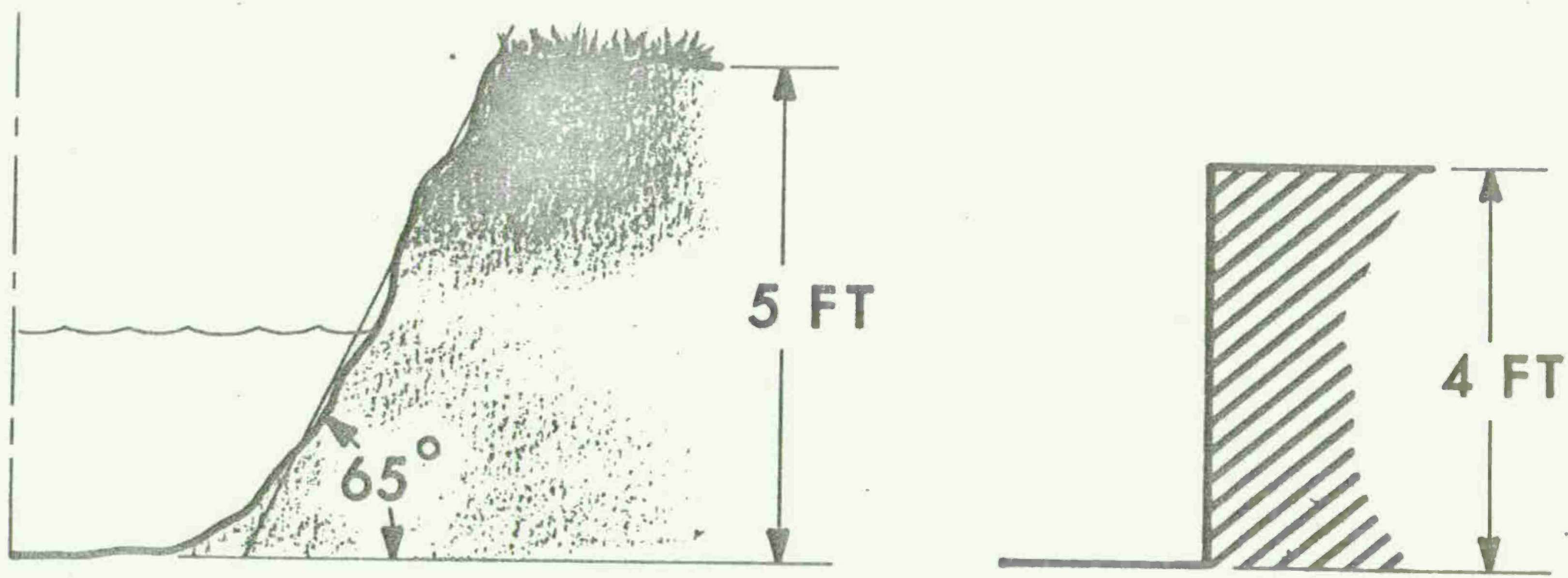


FIG. 10

EQUIVALENT OBSTACLES



BANK PROFILE EQUIVALENT STEP

FIG. 11

EQUIVALENT RIVER BANK

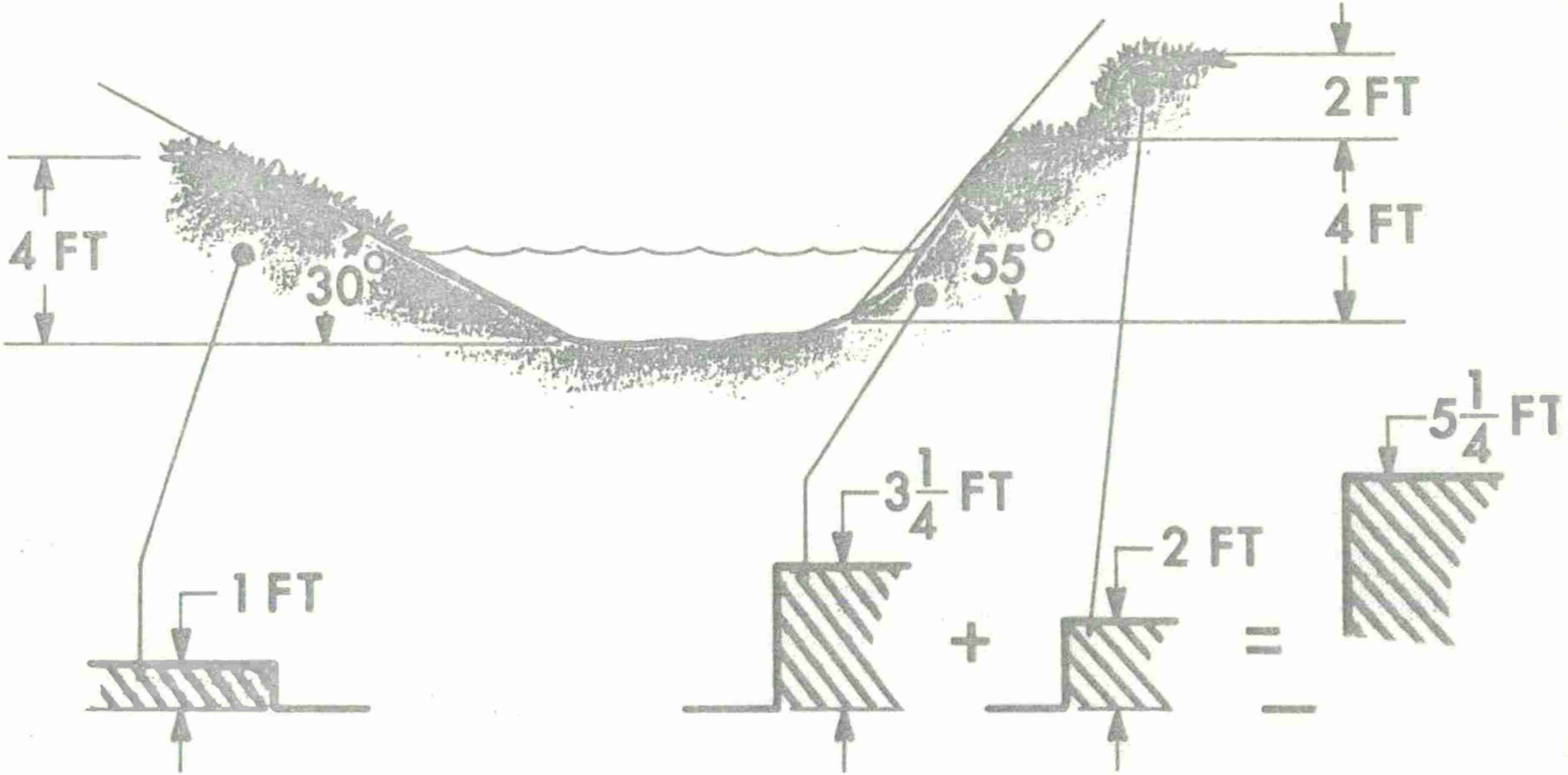


FIG. 12

OBSTACLE PERFORMANCE

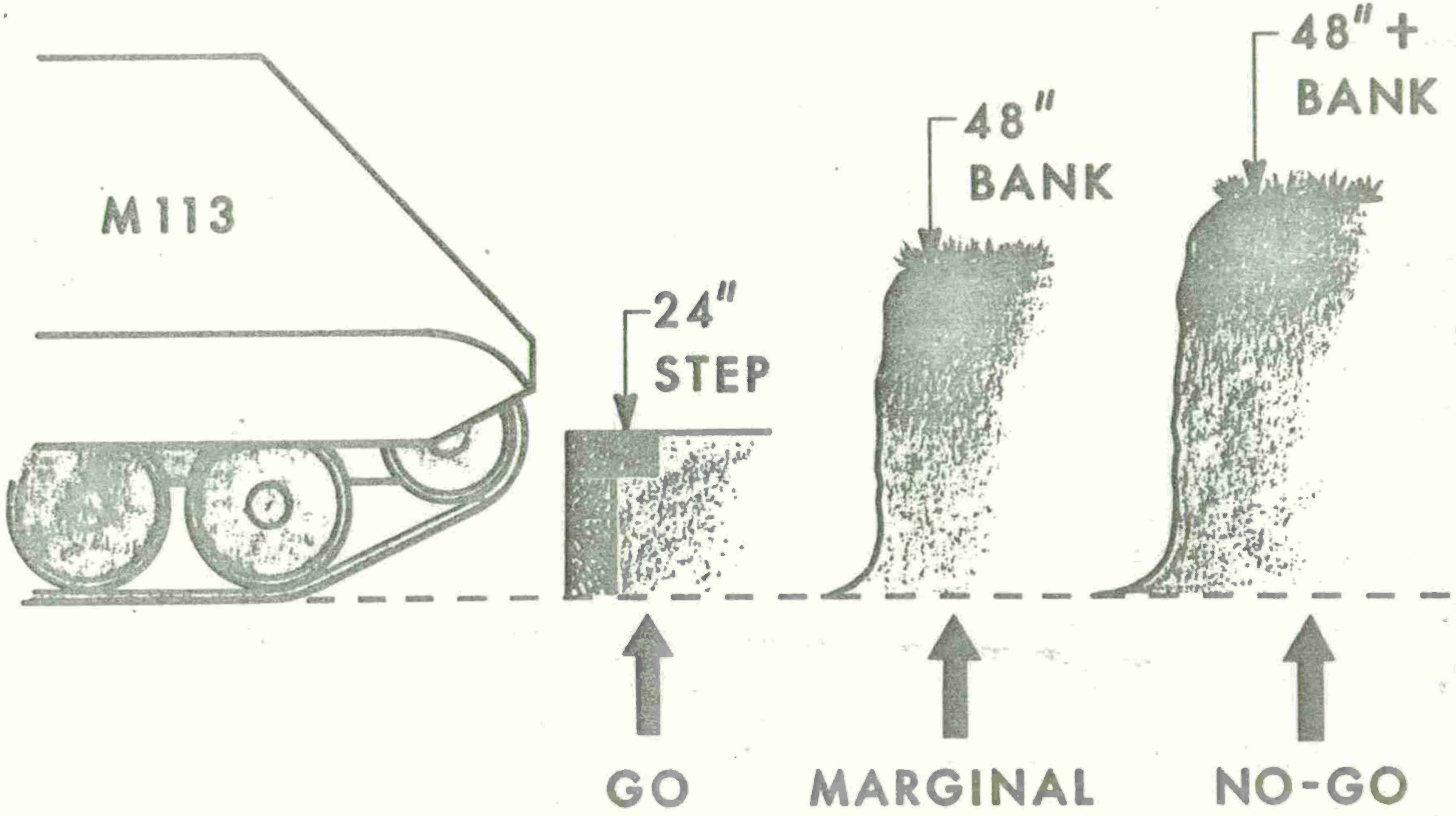


FIG. 13

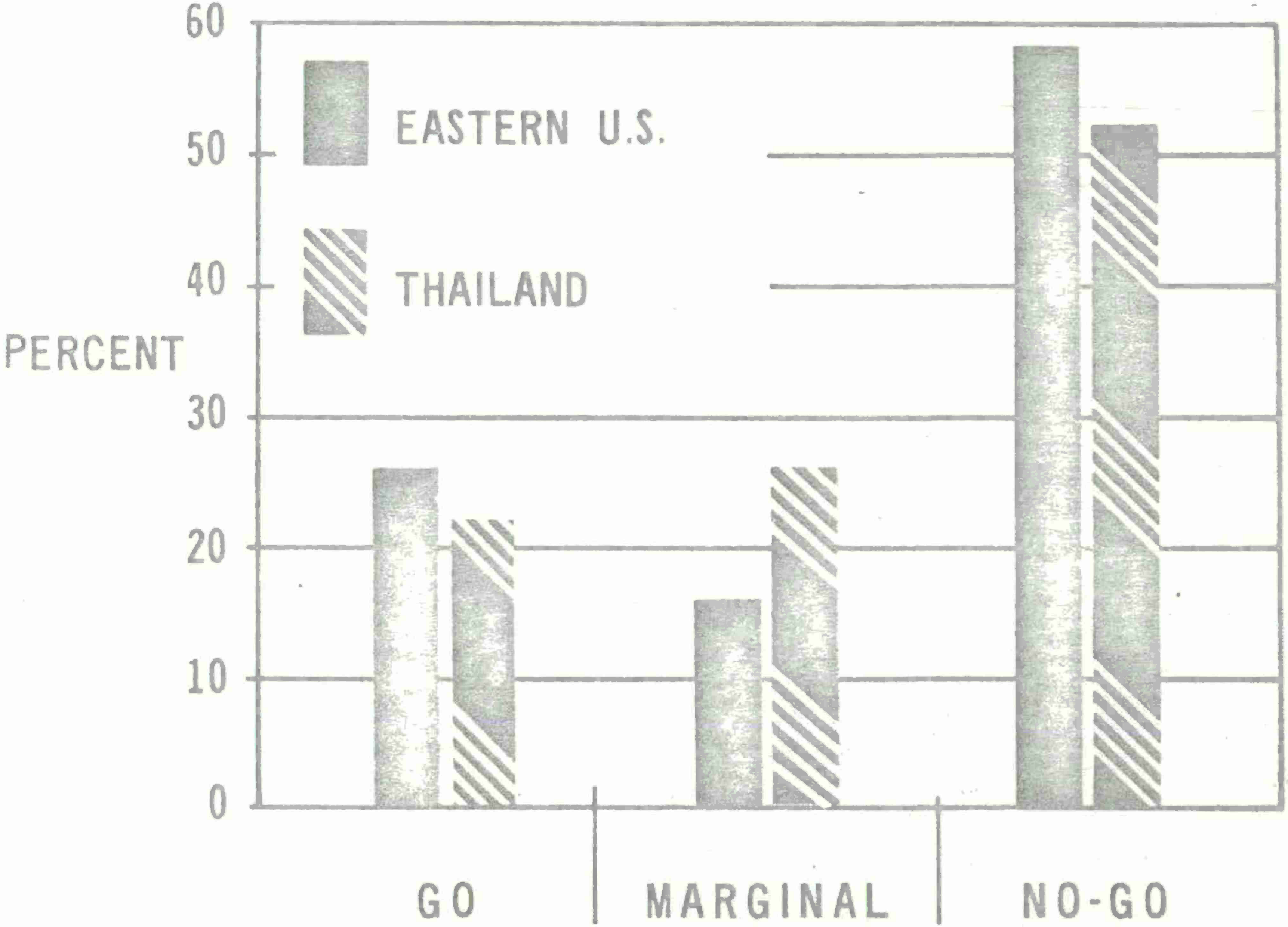

EASTERN U.S.
THAILAND
PERCENT
60
50
40
30
20
10
0
GO
MARGINAL
NO-GO

FIG. 14

Figure 15: M-113 Immobilized in the Clinton River.

Figure 16: M-113 Being Recovered with the Aid of Heavy Wreckers.

Figure 17: M-113 Exits on an Alaskan River Bank by Bulldozing and Excavating a Ramp.

Figure 18: Different Root Depths Appeared to Produce GO (Left) and NO-GO (Right) Conditions on What Was At First Thought to be a Uniform Bank.

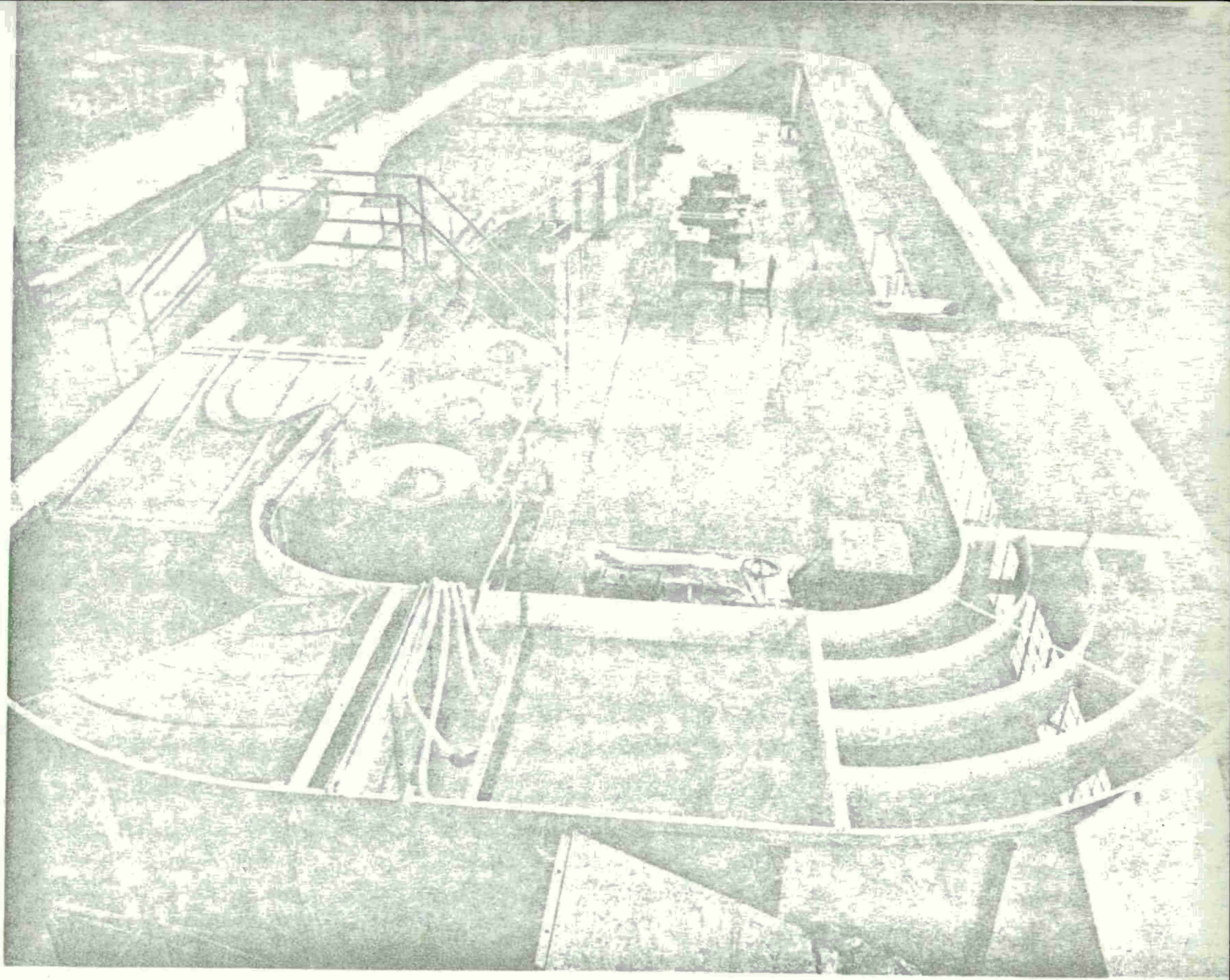
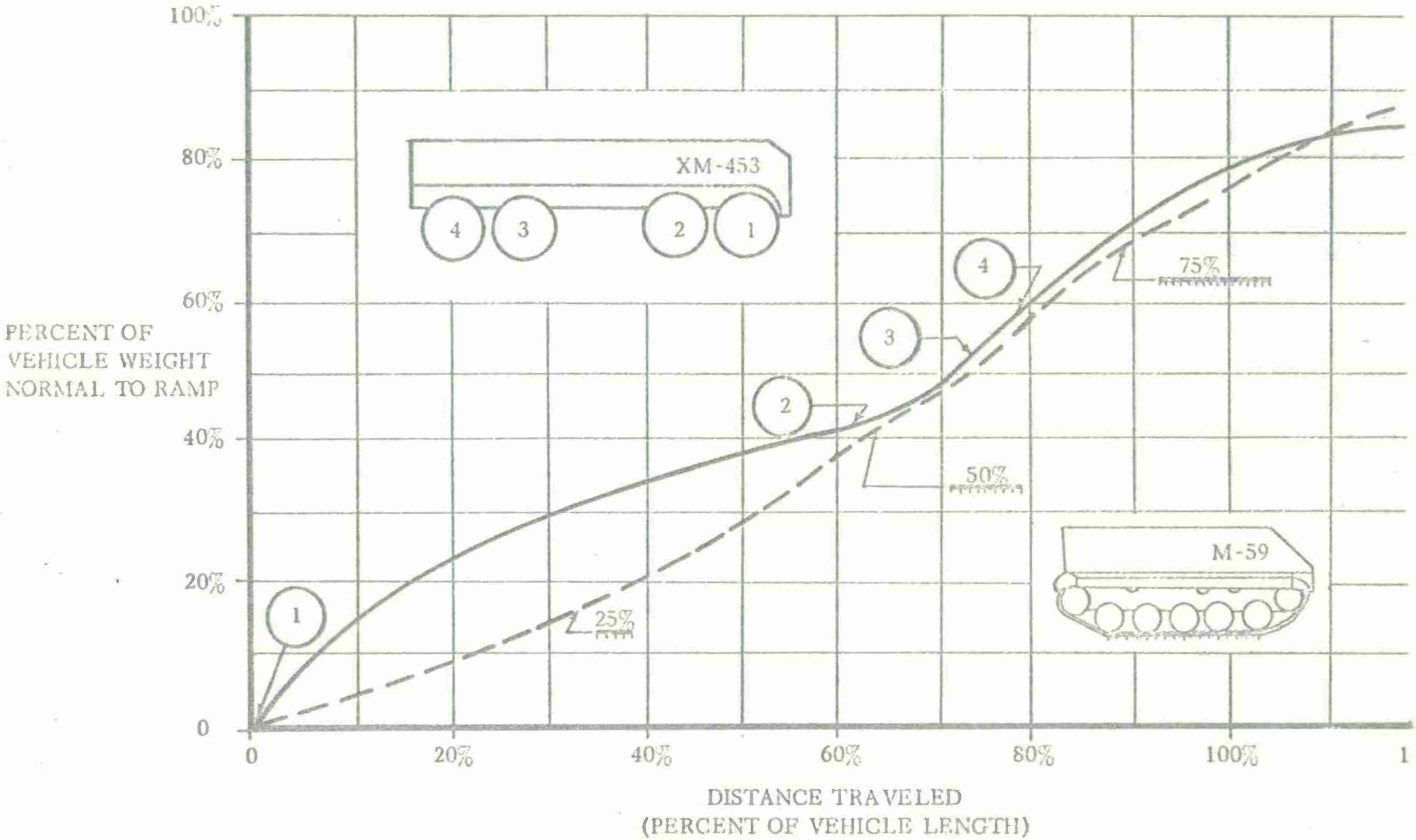


Figure 19: Land Locomotion Division's River Simulator Facility used to Analyze the Exiting Performance of Amphibious Vehicles.



Comparison of wheeled and tracked models exiting on a uniform ramp with a slope of approximately 27 degrees.

Figure 20

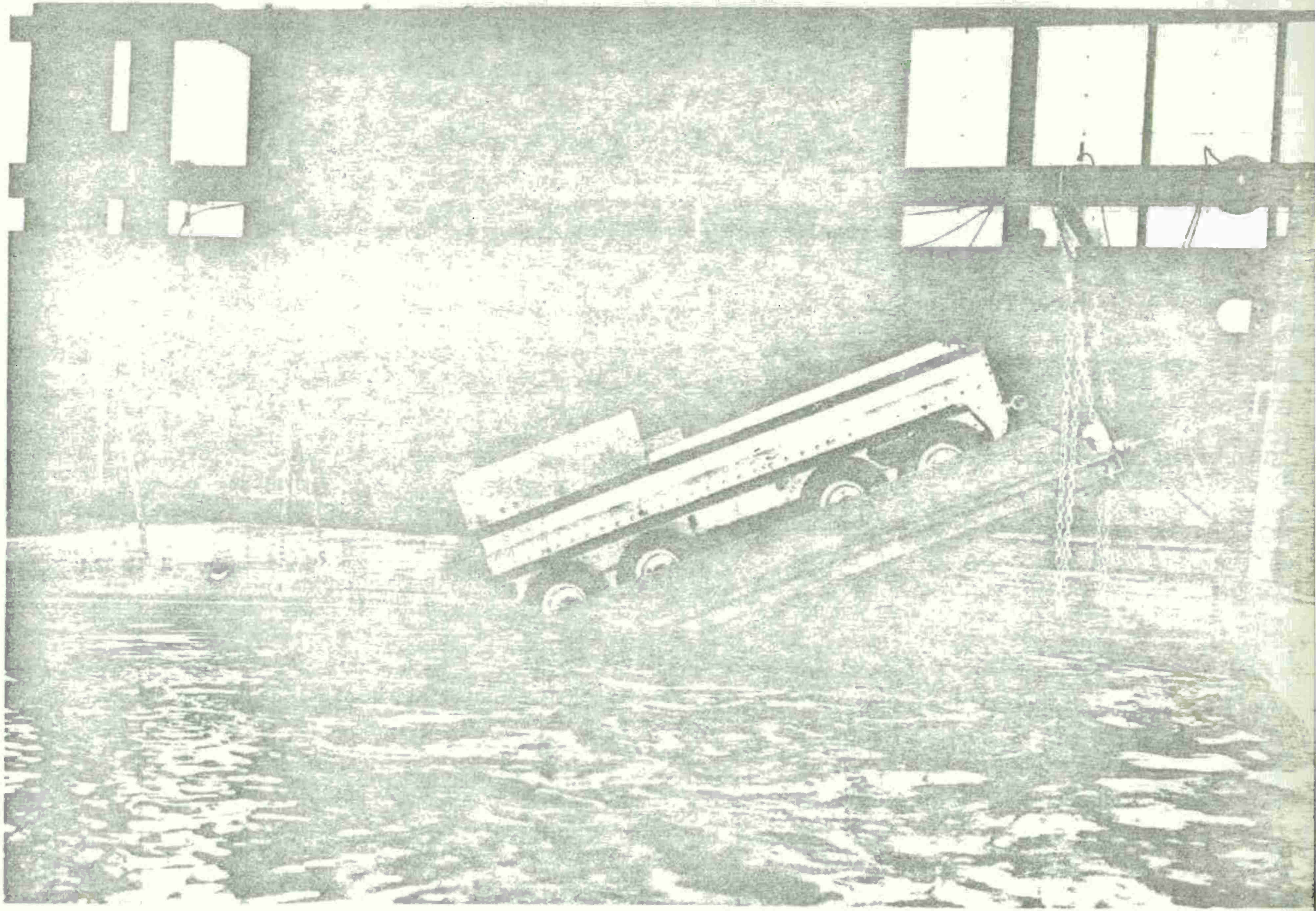


Figure 21 Load Measuring Ramp in the River Simulation Facility used to Measure Vehicle Exiting Performance. Shown with a 1/4 Scale XM-453, 8x8, 5-Ton, Cargo Truck Model.

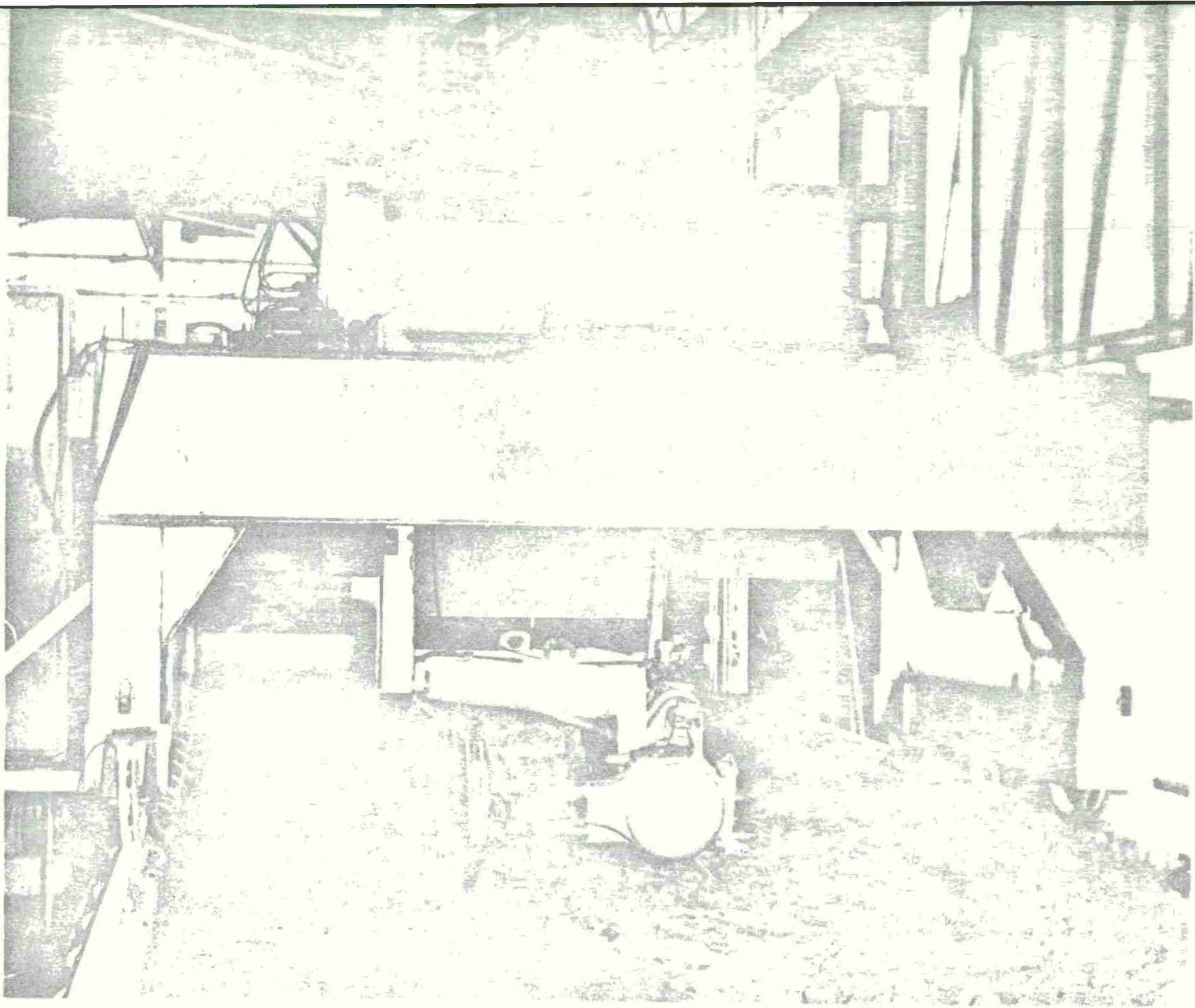


Figure 22 Land Locomotion Division Traction Testing Equipment. Shown here with the Track Dynamometer in Place with a Standard Track from a M-113 Armored Personnel Carrier.

COMPARISON OF RIVER SURFACE WIDTHS FOR EASTERN UNITED STATES - GERMANY - THAILAND

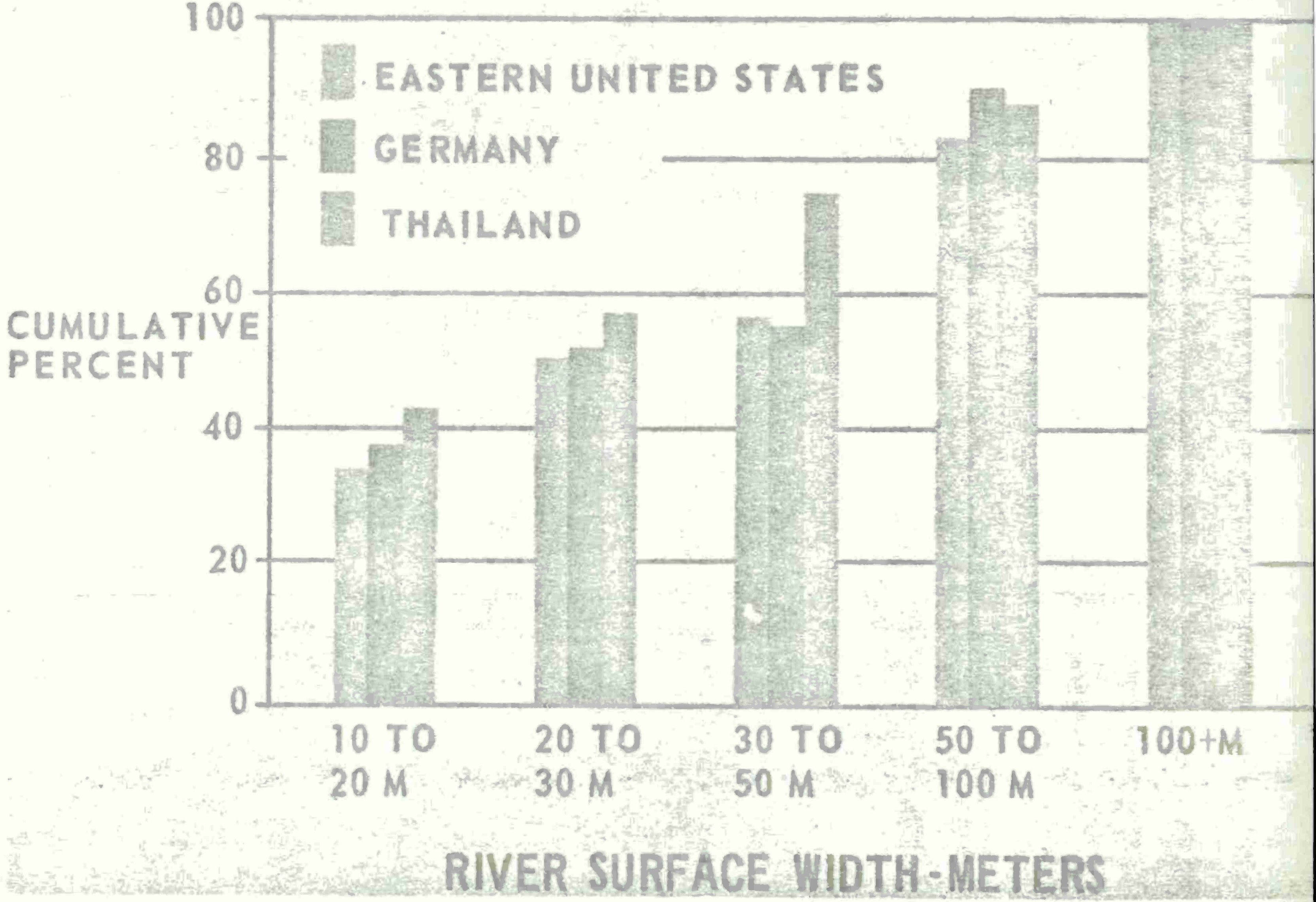


FIG. 23

CRITIQUE

Dr. Seth Bonder
The University of Michigan
Ann Arbor, Michigan

I would like to say it is a pleasure to have been asked to perform the critique again this year. I'd like to say that, but I really can't. I find the role of a critic a very difficult, time consuming activity which prohibits my participation in the evening "discussions" held on the first floor of the Jack Tar Hotel. After listening to my succeeding remarks, you may think I have no difficulty being critical. Seriously, though, it is an honor to be performing this function again.

I closed last year's critique with the comment that it be critiqued during this year's symposium. Unfortunately nobody did this, but I think it would have generated fruitful discussion on some important issues. Let me make a few comments regarding that critique. Marion (Bryson) instructed me to use a major portion of the critique time for a personal evaluation of the symposium and not just introduce the session chairmen. I think with that as the objective I more than adequately accomplished the mission. Last year's critique is markedly longer than the previous ones. Unfortunately, there are other measures of effectiveness, and accordingly, I will attempt to shorten this year's critique somewhat. I think that the format used in last year's critique was a reasonable one and I would like to use the same one again this year. In fact, I would like to make some comparisons between last year's activities and those of this year's symposium. It is interesting to note that out of the many analysts who received the symposium Proceedings, no one mentioned my inaccurate statement of the Central Limit Theorem. Perhaps nobody reads the critique, which may be good or bad depending on your point of view.

(Slide 1) This is the outline of the critique. I would like to review the attendance of the Symposium and its organization, and then, as I did last year, I'll discuss the papers regarding the number, type, subject, the time frame they addressed, and the methodology employed, and subjectively evaluate their quality. I would like to spend a few minutes discussing some general observations and then call on the session chairmen for their comments. As I did last year, I've

asked them to respond to two questions: (1) What did they learn during their session regarding the particular subject area, and (2) What are the remaining critical problems in that subject area that should be addressed?

Before beginning on this itinerary, let me note that, as with last year's symposium, no specific objectives were stated for the symposium. Accordingly, my comments are based on the premise that the objective of the symposium is the same as the global one I cited last year: to improve Army Operations Research.

(Slide 2) Let us begin by examining this year's attendance and comparing it to the attendance at the 1967 symposium. Per the footnote on the slide, let me point out that these figures were taken from the attendance lists and are not the actual number of attendees. Initially, it is relevant to note the reduction in the number of military personnel attending and, more particularly, the category in which this reduction is evidenced. Three attendees were of General rank, the same as last year, the full Colonel's increased by three, and there is a large reduction in the category I called "other". This category includes Lieutenant Colonels and below, the category which I last year defined to be the "working class" of OR analysts. It is somewhat disappointing to see the reduction in working level analysts because, I think, a major mechanism for improving Army OR lies in the education of the young analysts. If they are not permitted to attend the symposium, we eliminate an effective mechanism for improving Army Operations Research.

Colonel Burton noted that one of the original objectives of the Army OR Symposium was to provide a means of getting acquainted with our colleagues. I don't think that objective was fulfilled at this symposium since many of us knew each other prior to this meeting and, in fact, interact frequently throughout the year. I personally am acquainted with better than fifty per cent of the attendees and believe that figure would apply to many of you. This point, of course, is just a reflection of the fact that most of the attendees are senior OR analysts or administrators.

One last point on the matter of attendance. It is relevant to note the absence of a significant number of people from the Office of the Assistant Vice Chief of Staff. This is one of the largest OR/SA offices within the Army, consisting of a reasonably large number of new analysts who could benefit from this symposium. The presence of three people from that

office is rather a poor representation of what, to my knowledge, is expected to be a senior OR/SA office within the Army. In summary, I would suggest the Army support the symposium by sending more less-senior OR analysts for appropriate interaction with senior personnel as a means of improving Army Operations Research.

I would like to digress from my outline for a moment and discuss the organizational structure of the symposium. This year there were ten paper sessions, five panel sessions, and one technical working group chaired by Dr. Balinski. The intent of the latter was to look at the question of what operations research methodologies are relevant to Army Operations Research. Although some of the ideas raised by Dr. Balinski this morning were very provocative, the working group was ineffective in accomplishing its stated objectives. The call for papers indicated that the theme of the symposium was "Systems Analysis in Operations Research". I don't really understand what that means but that is unimportant since, as I noted last year, themes are really artifacts. What we should strive for are good papers and good presentations independent of the theme orientation.

Last year I recommended that we have more time for papers. Thanks to the effectiveness of the Organization Committee we had ample time for papers this year. At a minimum, there was thirty minutes per paper. Some papers had the complete session, an hour and a half. This provided sufficient time for discussion and, in my opinion, the discussions, both in the panel and paper sessions, were interesting and fruitful. The sessions again this year were well integrated due primarily to the fact that the session chairmen were responsible for developing their own sessions. Some of the sessions were completely integrated--that is, there was only one paper.

(Slide 3) This slide presents a listing of both the number and types of papers. We note that the total number of papers dropped from 55 last year to approximately 41 this year. There was a large reduction in the number of invited papers and a small increase in the number of contributed ones. The classification of papers is similar to that used last year, although I did add some new categories. The first category, briefing-position papers, are papers that contain little if any OR content. Rather, they are specific office viewpoints on particular issues, typified by the OSD paper presented by Herrington, or papers that describe "what we do back home". I think a small number of papers of this type are needed in the symposium; however, because of the composition of this

particular audience, I felt that a number of them were ineffective. They were already talking to the initiated. I, and I am confident many of you, have heard the OSD viewpoint, approach, etc., many times before. An OSD position paper would be very effective if presented to a larger audience of junior analysts. I would premise that, in general, the value of position papers increases as the experience level of attendees decreases.

The "study" category includes papers which describe content of specific operations research studies which have been completed or are very near completion. Discussion of these papers comprises a major part of the critique and I will return to them shortly. Reduction in the number of study papers was accomplished by eliminating the "what are you doing?" papers initiated at last year's symposium. Although they were not very well done last year, the idea of presenting current problems to the community for information and possible assistance is an excellent one. Unfortunately, the authors devoted too much time on promises regarding what they were going to do as opposed to problem description. I thought the concept was a valuable one to the symposium and perhaps should be reinstated.

The tutorial papers were lessons in OR philosophy and methodology. These are typified by the papers presented by Walter Strauss and the one that I presented. They were intended to generate ideas on the application of new methodologies and point out problem areas in Operations Research.

There were six papers that I categorized as OR technique. These included truncated queueing problems, Monte Carlo sampling to evaluate the bivariate normal distribution, and others. I don't believe papers of this kind should be presented at the Army OR symposium. Rather, other vehicles such as the Operations Research Society of America meetings or the Design of Experiment Symposia appear to be more appropriate.

(Slide 4) This slide shows a classification of papers by subject category. I included in this scheme all the papers--that is, the position papers, the study papers and the panel presentations. Classifying papers in this manner is, of course, very subjective. There are only a couple of things we should observe from this listing. First of all, we appeared to fill the voids from last year and created a few others this year. In general, a large variety of subject matter was presented in the papers. The increased emphasis on force planning--going from 9% to better than 20% is significant and in the

right direction since this is a very cogent and important area. Another significant change is a decrease in counterinsurgency from 15% to 2%, essentially one paper. This change is in the wrong direction in that counterinsurgency is an important area requiring increasingly more study effort.

(Slide 5) This slide categorizes the papers according to the study time frame addressed--current operations or future ones (planning). The figures on the slide pertain to the eighteen papers that are classified as study papers. This year, 33% of the papers were on current operations (a 100% increase from last year) which I thought was in the right direction since we should spend more time on Southeast Asia problems. The figure, however, is misleading since three of the six papers in this category addressed problems relevant to current management systems. Of the three papers addressing Southeast Asia problems, only one did anything substantive--the paper by Bill Niskanen. It is worthy of special notice since it is Operations Research in the classic tradition and is also probably the most controversial paper presented at the symposium.

Papers describing studies which address future time frames dropped from 83% to 67%. Examining the subcategories--planning studies for forces, planning studies for future weapons and equipment, planning studies that address both simultaneously--indicates a move in the right direction. Last year there was a strict dichotomy between planning studies for forces and planning studies for weapon systems. This year, 17% of the papers (approximately three) addressed both questions simultaneously. I think this is a marked improvement.

I am a little confused about the lack of operational papers on activities in Southeast Asia. It is not clear to me what's perpetuating the lack of emphasis at the symposium on the Southeast Asia problem. Perhaps studies are being conducted but the analysts have insufficient time to present them or cannot obtain clearance to present papers with meaningful content. On the other hand, the absence of papers may actually be indicative of the lack of study effort in this area. A former student of mine who was in an Air Force OR group in Saigon indicated that he was not allowed to do any interesting and relevant OR studies. Reasons for this are beyond my knowledge; however, I'm surprised and concerned that Operations Research does not have a larger impact on activities in Southeast Asia.

(Slide 6) The next slide is a categorization of the eighteen study papers by the methodology employed. I have classified these into three common categories: experimental, war games and simulation, and analytic. There was a slight increase in the experimental approach presented at this symposium. The increase is due to the two papers in the small arms session and Bill Niskanen's paper. I would like to comment a moment on his paper which was essentially a regression analysis. There was mixed reaction to his study. The few young analysts in the audience thought that it was the most exciting activity they had seen since returning from the civilian universities where they were educated in Operations Research. In essence, the study is akin to those of the Morse and Kimball era of World War II. On the other hand, the senior analysts questioned the validity of the data he employed and hence the validity of his results. Recognizing that the latter viewpoint may be correct, I still think it was a study that was long overdue. As I noted, the study is reminiscent of the World War II Operations Research activities: the systems were available, operations existed, data could be collected, and operational inferences were made from these to improve the effectiveness of ongoing operations. The efficacy of this kind of OR study (in contrast with planning studies) is recorded in history.

Let's now turn to the second methodological area, war games and simulation. This year, approximately the same percentage of studies used this methodology as their basis. I won't expound on my personal prejudices regarding the overuse of Monte Carlo simulation since I've done this many times. If you are not aware of the pros and cons of employing this approach, let me refer you to last year's critique or the paper I gave in session VI-A which expounded on a few of these. The point I do wish to repeat is that there appears to be continual development of new simulations in specific areas where there is already an abundance of existing ones. Last year I noted the existance of four company level armored combat simulations. One paper this year described the development of another logistics simulation to add to the already crowded inventory of logistics simulations for the Army and Air Force. It appears to me the services unwisely waste scarce resources--technical talent and money--in re-inventing the wheel with an additional spoke. Last year I recommended that some agency be assigned the long term responsibility to collect, organize, and make available methodology for use in relevant military areas. To be effective, this should be done at DOD level; however, in the absence of such an interservice agency, it would be valuable for the Army to do something

along these lines.

(Slide 7) The final slide is an attempt to give an overview of the content of the eighteen study papers. It is my subjective way of saying study quality. The quality of the study can, in a rough sense, be appraised by considering some basic elements requisite to a study. These include problem definition and formulation (not shown on the slide but which I will discuss shortly); model development; use of data for either model development, as input or verification; a sensitivity analysis to determine the effect of incorrect input data or incorrect model assumptions; and finally a statement of conclusions and recommendations based on the analysis. Examination of the figures indicates that better than three fourths of the studies employed some form of model in their analysis, the percentage being slightly higher than last year. The use of data has increased by 50% over last year, the increase coming primarily in its use as input to the models. The validity of the data used is, of course, another matter. My impression from discussing the subject with many attendees of the symposium is that the credibility of the data is highly questionable. The combination of low percentages in verification and sensitivity analyses is somewhat disappointing. Recognizing the difficulty of verifying many of the models we employ sans data, we should run a sensitivity analysis to determine the effect of errors in model structure and errors in input data. The figures suggest that this activity is not being performed. I don't think I need dwell on the credibility of recommendations, especially recommendations in the form of specific numbers, that result from such studies.

The large increase in the percentage of conclusions and recommendations noted in the papers would imply an associated increase in the number of completed studies presented at this symposium. A major recommendation of last year's critique was that the symposium should contain papers on completed studies rather than promises. The 55% figure initially suggested a marked improvement of the papers in this respect. Unfortunately, the figure is spurious. Many of the papers presented conclusions and recommendations based on incomplete studies. Many of the models used in the studies are still under development. The one that comes to mind is the paper presented by General Phillips on the FORWON Study. If I remember correctly, he indicated that the model is a conceptual prototype; however, discussions with RAC personnel indicated that conclusions and recommendations for this year's budget were generated by the model. The credibility of such

conclusions would again be highly questionable, over and above the credibility problem associated with lack of model verification and sensitivity analyses.

Although specifically omitted from the slide, all study presentations were lacking in that they failed to describe adequately the problem definition and formulation phase of the study activity. This is a strange paradox, expecially when one considers the panel discussion entitled "OR/SA, What is it?" The key point that emerged out of that session was the fact that a systems analyst is an individual who is capable of structuring problems. Given (a) that the global objective of this symposium is to improve Army Operations Research and (b) that one way of accomplishing this objective is to expose young analysts to the experience of senior analysts, why are the presentations devoid of problem structuring activities? Nobody discussed the rationale for selecting a particular methodological approach (experimental, simulation, analytic) to a problem. No one discussed the rationale for selecting particular variables to include in the study. Nobody discussed the rationale for making specific assumptions. I would strongly recommend to the Organization Committee for next year's symposium that authors be specifically requested to describe these activities as part of their presentations.

At this time, I would like to discuss some observations about the symposium and Army Operations Research in general. It was stated at this symposium that..."a good study produces intuitively appealing results". I do not think that is correct. In fact, it is our inability to intuit correct answers that is precisely the reason we perform systems analysis studies. If we consider the combat situation,it is precisely the interactions among the weapon system capabilities, the environment, the tactics employed, and organizational structures which prohibit intuiting the effectiveness of combat units. Intuition or "expert judgment" is based on experience which proves adequate when dealing with relatively simple phenomena in times of stable technology but has many dangers in light of the complexity of current and anticipated systems. If anything, studies will develop intuition.

A number of participants at this symposium suggested that there are three types of analysts--engineering OR, business OR, and the systems analyst. This trichotomy is at best misleading because associated with it was the implication that the business OR analyst and the systems analyst can formulate problems while the engineering OR analyst lacks

this capability. Associated with this was the impression that the analyst who is technically trained, mathematically trained, is incapable of finding and structuring problems. By itself, this implication is of little interest and can do no harm. However, I am concerned that the implication will lead to the converse statement that one must not be technically trained to be a systems analyst. Education and hiring policies resulting from this statement could rapidly lead to a core of systems analysts possessing little or no scientific base. I don't accept the premise that it only requires intelligence to be a systems analyst. I am confident that poets and musicians are intelligent. I don't think they could effectively function as systems analysts. I would suggest that it is a necessary condition for systems analysts to be intelligent, but not a sufficient one. Education and experience in quantitative scientific approaches are needed.

The panel session on OR/SA devoted a considerable amount of discussion to determining the nature of the field. The result of those discussions was very disappointing in that it left a tainted image surrounding the OR/SA field. There was a conscious effort by many of the participants to clearly not identify themselves as operations researchers or systems analysts but rather economists, chemical engineers, physicists, and practitioners of other fields of endeavor. This is a sad commentary when one considers the fact that the participants are experienced senior analysts charged with the responsibility of developing and integrating OR/SA activities into the military services. This attitude has a completely destructive effect on the inexperienced but well-trained and enthusiastic analyst returning from civilian educational institutions. It is important that new analysts be encouraged to participate in and contribute to the development of Army OR. Failure to recognize OR as more than a "military staff study" will in the long run adversely affect the supply of creative analysts--the most important ingredient of effective operations research studies.

I would like to make one final observation--this one regarding the Army OR program in general. There appears to be a continuing, and perhaps increasing, emphasis on conducting OR studies to substantiate requirements to O.S.D. rather than studies to determine requirements. This distinction is an operational one which can have a marked effect on the quality of Army OR studies. Studies to substantiate requirements, perhaps a priori management positions, stifle the analyst and destroy the creative elements associated with good operations research. This rigidity, the absence of an intel-

lectually free study environment, was noted by a number of senior personnel during the symposium. I believe the quality of Army OR can be improved, not by looking upward to O.S.D. but rather by focusing effort downward within the Army study program. This effort should take the form of (a) the establishment of an atmosphere for creative OR at all Army levels, and (b) the establishment of a mechanism by which senior analysts (perhaps those at D.A. and other command staffs) can provide constructive guidance in the formulation and conduct of OR studies. The latter will provide efficient use of the scarce experienced analyst resources and will contribute to the necessary education and development of new OR talent. In my opinion, the result of such efforts would produce quality studies to determine Army requirements and substantiate them to O.S.D.

In summary, I feel that this symposium has not adequately employed a major means at its disposal of improving Army OR--the education and development of new OR analysts. Instead, it has created a false impression that OR is not a professional field in itself but rather is akin to a military staff study whose results must be "intuitively appealing." One attendee, unfortunately a prospective user of OR, is leaving here convinced that OR is "a gimmick to make money." Our discussions lead one to believe falsely that technical education is a roadblock to successful OR rather than an asset. Army OR studies do not appear to be improving at a rate commensurate with the needs. Activities at this symposium, and other observations of mine, leave the impression of an almost purposeful stifling of OR activities by management, perhaps with the hope that the requirement for its use will fade with a new administration. I don't believe it will; but if it does, it will be a backward step in the management of our military resources.

DISCUSSION

Dr. John Honig: ("Weapon Systems Analysis")

Walter Strauss's talk was of general interest and well presented. It was not nor intended to be provocative.

The position of the session on developing measures of unit effectiveness may have been too early in the program phase.

Rufus Ling described the mathematics in somewhat too great a detail without sufficiently discussing the problems of applying the technique to unit combat effectiveness. Hopefully, these relationships will be better established either by us or by the CDC Contractor within the year.

Professor Bonder gave a very interesting talk on a distantly related subject.

The work that needs to be done was outlined in the chairman's remarks.

Dr. Jack Borsting: ("Operations Research Education for the Military")

Although the services have been increasing their requirements for OR/SA trained officers, both at the specialist's and "executive's" levels, due to the shortage of people and money, the quotas for educational programs are not being met by the various services. It will take many years if current trends continue before the number of trained people catch up with the requirements. When, in the future, the services have sufficient trained officer analysts, working with skilled civilian analysts as a team, the overall quality of OR/SA studies should improve.

The utilization of OR trained officers varies slightly in the various services. For example, the Marine Corps has a higher percentage of billets of an operational nature.

Mr. Oscar Wells: ("Tank Anti-Tank Assault Weapons Systems")

The session was a well-integrated session. It was a presentation of a major CDC study underway at the Combat Developments Command Armor Agency located at Fort Knox, Kentucky.

The title of the paper was: "Some Operational Research Aspects in Selecting Optimum Tank, Anti-Tank, and Assault Weapons Candidates".

The paper was presented by Major Jim Eddins and the discussant was Colonel Harold Fleck.

The thought behind this session was to present in some detail a major study effort and allow sufficient time for discussion.

The paper was well presented and generated many questions as evidenced by the fact that at the end of a 40-minute question period some questions were still being asked.

One area for consideration that came out of the discussion was the thought presented by Dr. Bonder in an earlier session of using an analytical approach to reduce the required simulation time. In this study each combat set requires about 9 hours of CDC 3300 computer time with a total estimated machine requirement in excess of 1000 hours. As a matter of interest the study group is working on such an analytical approach and are currently in the test phase.

Areas of considerable interest expressed by the group were:

1) The cost model and how peacetime costs were calculated.

2) The ability of the model to play Tac Air and Artillery.

3) Sensitivity analysis of combat range variations and threat mix variation.

4) Inter-relationship and correlation required by use of two combat simulation models used in the study.

Dr. A.L. Slafkosky: ("Small Arms/Small Arms Units")

The objective I set for this Panel was not to present meaningful OR or SA studies reports, but rather to present (a) a concept which almost intuitively has an obvious appeal (in this case that of a small arms family of weapons) and (b) a couple of examples of attempts made by two of the services to come to grips with portions of the problem of convincing themselves as to what weapons should comprise the family and what impact these weapons would have on the units who utilize them, and how best these units should be structured. Moreover, I also hoped to make the group realize how difficult it is to collect meaningful data necessary on inputs to any good analysis. I had also hoped to show that the nature of the data collection is not haphazard, but depends to no small extent on the primary of the measures to be used in the study and how these are interrelated.

I do not think this last notion ever got across, primarily because we did not have enough time to bring the discussion around to this point.

In this post-presentation session, I noted (as I've noted almost ad nauseum in other such meetings) that too many people only listen to presentations or even discussions on them with ears which effectively filter out what their preconceived notions want to filter out, often missing the forest for a particular tree.

In so far as a certain amount of interest & discussion was generated and interest renewed in this problem area, the session was successful.

Mr. Robert Triplett: (Contributed Papers)

Major Hess' paper presented a methodology for evaluating the relative effectiveness of defense versus proliferation as a function of the enemy probabilities of killing hard and soft silos. The techniques developed can be applied to any combination of costs, attacker weapon accuracies and lethalities, and defense interceptor reliability to determine the cost

effectiveness of competing alternatives. Major Hess feels that his model will be of help in future Army procurement of missile system and equipment.

In Mr. Wight's paper the prime purpose of the operations research was to determine the weapon environment to which communication and combat surveillance equipment would be exposed on a nuclear battle field. The basic problem resolved into determining the distribution of equipment within a given nuclear weapon environment and estimating the effects of this environment on the equipment. From an analysis of this type, it was possible to determine the equipments that would be in the "grey areas" between complete destruction and no effect; and hence be able by corrective measures, to have their susceptibility to atomic weapons decreased. The operation of the equipment in these grey areas, the corrective measures to be taken to decrease their susceptibility to the atomic weapons effects, and the presentation of these corrective measures as techniques and practices to be followed by the electronic design engineers is presented.

Things which Mr. Wight learned during his research were:

a. Blast and thermal effects are not as damaging over all as radiation.
b. Equipment can very often be softer than man.
c. Balanced hardening should be utilized with electronics equipment and systems per se.
d. The battle area can be war gamed to give the systems developer the threat he will have to protect against.

For the future, OR should carry on extensive war gaming exercises, picking out different terrain, Army configurations, and weaponry. Without further test programs, this is necessary in developing the requirements of the QMR.

Major Otto's paper argued that real money can be saved by small OR/SA studies at the operating level, and presented models for a Saigon Area Port Clearance System, an aircraft repair parts supply system, and a value judgment model for Army equipment systems.

Major Otto is strongly in favor of a continuing effort to add the capability to use the OR/SA approach at lower operating levels.

CRITIQUE OUTLINE

ATTENDANCE

ORGANIZATION

PAPERS

- NUMBER
- TYPE
- SUBJECT
- TIME FRAME
- METHODOLOGY
- QUALITY

GENERAL OBSERVATIONS

SESSION CHAIRMEN COMMENTS

ATTENDANCE*

	1967	1968
TOTAL	200	175
MILITARY	83	66
GENERAL RANK	3	3
COLONEL	20	23
OTHER	60	40

* FROM ATTENDANCE LIST

PAPERS

	'67	'68
TOTAL	55	41
INVITED	46	26
CONTRIBUTED	9	15
TYPE		
BRIEFING/POSITION	14	11
STUDY	29	18
"WHAT DOING"	12	0
TUTORIAL	0	6
TECHNIQUE	0	6

	%	
	'67	'68
SYSTEMS ANALYSIS / FORCE PLANNING	9	21
COUNTERINSURGENCY	15	2
COMBAT MODELS	0	2
WPN PLANNING/EVALUATION	24	20
WAR GAME/SIMULATION	9	9
INTELLIGENCE/THREAT	6	5
MISSILE/AIR DEFENSE	0	2
LOGISTICS/MOBILITY	15	9
C_3	4	5
OR EDUCATION	4	9
MANAGING OR/SA EFFORT	6	0
MANAGEMENT SYSTEMS	0	7
HUMAN FACTORS	8	0
MISC.	0	7

STUDY TIME FRAME

	% '67	% '68
CURRENT OPERATIONS	17	33
SEA		(17)
MANAGEMENT SYSTEMS		(16)
PLANNING	83	67
FORCES	(27)	(17)
WPNS/EQUIPMENT	(49)	(33)
BOTH	(7)	(17)

STUDY METHODOLOGY

	% '67	% '68
EXPERIMENTAL	7	22
WAR GAME / SIMULATION	61	56
ANALYTIC	32	22

STUDY CONTENT

	% '67	'68
MODEL DEVELOPMENT	74	83
USE OF DATA	45	67
MODEL DEVELOPMENT	37	22
INPUT	0	45
VERIFICATION	8	6
SENSITIVITY ANALYSIS	22	11
CONCLUSIONS/RECOMMENDATIONS	22	55*

* 50% IN-PROCESS, BUT WITH RESULTS

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13. ABSTRACT

This is a technical report containing papers presented at the Seventh Annual U.S. Army Operations Research Symposium. No one area is stressed, so there is a great variety of topics considered. We mention a few: An automated force planning system, intelligence applications of operations research, weapon systems analysis, operations research education for the military, tank anti-tank assault weapons systems, small arms/small arms units, war gaming.

14. Key words

systems analysis
operations research
war gaming
small arms weapons
force planning
cost effectiveness
contingency planning
weapons systems